IN THE UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF OKLAHOMA

STATE OF OKLAHOMA,	)	
	)	
Plaintiff,	)	
	)	
v.	)	**Case No. 05-cv-329-GKF(PJC)**
	)	
TYSON FOODS, INC., et al.,	)	
	)	
Defendants.	)	

DECLARATION OF ROGER L. OLSEN, Ph.D.

I, Roger L. Olsen, Ph.D., hereby declare as follows:

A. BACKGROUND

1. Since February 1985, I have been an employee of Camp Dresser & McKee Inc. ("CDM"), an environmental consulting firm. I currently hold the position of Senior Vice President and Senior Geochemist with CDM. My educational background includes a Bachelor of Science degree, with high distinction in Mineral Engineering Chemistry, from the Colorado School of Mines in Golden, Colorado, in 1972 and a Doctor of Philosophy degree in Geochemistry from the Colorado School of Mines in 1979.

2. From 1975 to 1978, I was an instructor in chemistry and geochemistry at the Colorado School of Mines. I taught courses in general chemistry and quantitative analysis. From 1978 to 1979, I was a senior research chemist with Rockwell International at the Rocky Flats plant. I was responsible for evaluating methods to clean up contaminated soil at Rocky Flats and other Department of Defense facilities. From 1979 to 1983, I was a project supervisor with D'Appolonia Consulting Engineers. In 1983, International Technology (IT) acquired the portion of D'Appolonia for which I worked. At D'Appolonia and IT, I performed many

EXHIBIT
"D"

evaluations related to environmental contamination. In 1985, I joined CDM where I continued to evaluate environmental contamination. I have extensive experience in performing environmental investigations and studies, evaluating the environmental fate and transport of chemicals in the environment and determining the cause or source of contamination in the environment. In all, I have worked on or evaluated environmental conditions at over 500 sites. I am the author or co-author of over 120 publications/presentations and over 400 technical reports relating to environmental contamination.

3. In November 2004, CDM was retained by the Oklahoma Attorney General to perform an investigation concerning environmental contamination found in the Illinois River Watershed ("IRW"). I have been CDM's Project Technical Director since inception of the project. In this capacity, I have helped plan and direct a systematic investigation of the environmental contamination found in the IRW. This investigation included collection and laboratory analyses of poultry waste, soils, surface waters, groundwaters and sediments throughout the IRW.

B. Opinions of Glenn W. Johnson, Ph.D., P.G.

4. I have reviewed the opinions of Glenn W. Johnson contained in his expert report (Rebuttal Report, Principal Components Analysis of Geochemical Data from the Illinois River Watershed, Northwest Arkansas and Eastern Oklahoma, November 21, 2008) and his deposition (Deposition of Glenn Johnson, PhD, February 24 and 25, 2009).

5. In his Rebuttal Report, Dr. Johnson offered the opinion that total concentrations and geochemical partitioning control the surface water quality data (page 5 of Johnson's Rebuttal Report). During his deposition, Dr. Johnson discussed that opinion (pages 77-78 of Johnson

deposition):

77

A Item No. 6 is Dr. Olsen failed to recognize the influence of total concentration and geochemical partitioning on the PCA. By assuming at the outset that it was a source-controlled system, I think he missed the two primary controls on surface water in 11:08AM

78

this system, which is -- the degree to which -- well, first of all, total concentration and second, the degree with which how chemicals redistribute themselves in the environment according to their affinity for being bound to particulates or being in 11:08AM
a dissolved phase. 78
Q This is your muddy, salty water?
A Yeah, it's the shorthand that I used within the report, but, yes.

Dr. Johnson further elaborated on this opinion on page 137 of his deposition:

137

A Well, for one, these things that I'm telling you I was not asked to do, I believe he was. He was 01:35PM
asked to put together a PCA-based model that identified sources. Number two, when I redid the PCA, I came to the conclusion, based on my reanalysis, that that was driving -- the signal that was driving the two principal component model that 01:35PM
he presented was related to the basic geochemical affinity of the analytes, specifically potassium, chloride, sodium, sulfate, iron and aluminum, and so the PCA story is not a story related to source, as much as it is a story related to chemical affinity. 01:36PM

6. In the above opinion, Dr. Johnson disagrees with my opinion that the Principal Components Analysis (PCA) can be used to identify land application of poultry waste and waste water treatment plant (WWTP) discharges as the dominant sources of contamination in the IRW. Dr. Johnson states that geochemical processes and not contaminant sources are the controlling

factors in the PCA and the surface water quality data. In Johnson's opinion, the processes that are supposedly controlling the water quality data are simply affinity or adsorption of chemicals (including phosphorus) to particulates (or total suspended sediments). That is, the suspended particles and total concentrations (not the dissolved concentrations) are the controlling factors.

7. In order to conclude that contaminant sources are not an important controlling process (i.e, "…the PCA story is not a story related to source"….), one needs to evaluate the contaminant sources (including phosphorus) in the IRW. However, Dr. Johnson did not evaluate any contaminant sources in the IRW as shown by the following questions and responses in his deposition.

80
Q Okay. Are you offering any opinions as to
what the major sources of phosphorus are in the
Illinois River watershed?
A No. 11:10AM
Q How about sources of bacteria, same question?
A No.

136
Q That's fair enough. I mean, you are only
responsible for what you were asked to do. Let me
ask another question. Did you do any evaluation of
the amount of waste that would be generated by each
of the sources you just read from in your report? 01:34PM
A No, I've not.

142
Q Do you know what the sources of phosphorus are
in the IRW? 01:42PM
A No, I don't.
Q Do you know what the sources of bacteria,
fecal bacteria are in the IRW?
A No, I don't.

143
Q Did you do any evaluation of sources for
phosphorus in the IRW at all, review any literature,

for example?
A There's literature cited in my report. Was your question specific to IRW? I'm sorry? 01:44PM
Q Yes, yes. Sources of phosphorus in the IRW.
A No.

182

Q I think I've covered this. I want to make sure. Do you know how many different sources of nutrients there are in the IRW? 02:56PM
MR. GEORGE: Object to form, asked and answered.
Q Sources in water in contamination?
A Sources of -- 02:56PM
Q Nutrients.
A No, I don't.

205

Q Okay. Did you do a similar evaluation; did you do an evaluation of the IRW geology or hydrogeology in relation to fate and transport of --
MR. GEORGE: Object to the form.
Q -- potential sources of contamination when you did your evaluation? 03:38PM
MR. GEORGE: I'm sorry. Asked and answered.
A This goes back to the earlier questions. I was not asked to do this. There were other experts on the team that were doing it. 03:38PM

435

Q Did you try to determine what the other sources of phosphorus were in the watershed?
A I identified -- I know what the -- a list of potential sources. With this analysis, I was not able to do that and I was not asked to do this by my 01:19PM

436

client.

8. Without basic understanding of the important sources of contamination, Dr. Johnson's overlooks the amounts and levels of contamination in the IRW waters and wrongly concludes that the observed water quality data are the result of natural processes. As a result, Dr.

Johnson's opinion that sources are not a controlling the IRW water quality do not fit the available data collected in the IRW. The studies by the United States Geological Survey (R. Tortorelli and B. Pickup, 2006, Phosphorus Concentrations, Loads, and Yields in the Illinois River Basin, Arkansas and Oklahoma, 2000-2004) state that the IRW is highly contaminated by phosphorus (page 1): "Estimated mean flow-weighted concentrations were more than 10 times greater than the median (0.022 milligrams per liter) and were consistently greater than the 75th percentile of flow-weighted phosphorus concentrations in samples collected at relatively undeveloped basins of the United States (0.037 milligram per liter)". Dr. Johnson is apparently unaware of the available data and levels of phosphorus contamination in the IRW waters as illustrated by the following questions and responses:

469

Q Is it your opinion, sir, that total dissolved 02:25PM
solids -- excuse me -- total dissolved phosphorus in
an Illinois River stream is low at .2932 parts per
million?
A I don't know what number I would put on low
versus not low. The .2 -- what number did you say? 02:26PM
Q I'm just reading the average here as .2932. I
thought I heard you say that you characterized these
phosphorus levels as low.
A Low in the context of the --
Q Well, it's low in the context we looked at for 02:26PM
edge of field?
A Yes, yes.
Q And edge of field was 8.4.
A I forget what number is the -- is considered,
and I don't know even know they use this term, an 02:26PM
action level, so I'm not sure where the .2932 fits
in that scale.
Q Do you know what the action level is for
phosphorus in the IRW according to Oklahoma law?
MR. GEORGE: Object to form. 02:27PM

470

A No, I don't.
Q Would it surprise you to know it was .037?
MR. GEORGE: David, are you representing that's an action level?
MR. PAGE: Well, I'm just using his terminology. 02:27PM
MR. GEORGE: Well, are you -- you said did you know the action level is.
A And I prefaced action level saying I don't know if this is an accurate term. 02:27PM
Q Well, do you mean by like a phosphorus criteria?
A Yeah.
Q Okay. Yes, I'm representing that 0.37 [sic] is the phosphorus criteria for scenic rivers in the Illinois River watershed. 02:27PM
A Yes, that would be above that. The .2392 would be above that level.
Q Well above it; correct?
A Yes.
Q So in that context, it wouldn't be a low level of phosphorus, would it?
A You are correct.

9. On page 470, line 14 above, "0.37" should be "0.037"

10. In addition to the fact that Dr. Johnson did not evaluate the sources of phosphorus in the IRW and does not understand the sources or phosphorus levels in the IRW, he also does not understand and is not qualified or experienced to evaluate the physical and geochemical processes that he opines are controlling nutrients and water quality in the IRW. He also has no experience with agricultural pollution, nutrients or bacteria as shown by the following questions and responses:

87

Q Okay. Have you ever worked on -- I'm going to say a case -- I'm going to mean an investigation, a source investigation -- involving agricultural pollution other than this case? 11:21AM
MR. ELROD: Object to form.

A Not that I recall. 11:22AM
Q How about nutrient pollution?
MR. GEORGE: Object to form.
Q Have you worked on a case other than this case
that involved nutrients as the contaminants of
concern? 11:22AM
A Not that I recall.
Q How about same question with regard to
bacteria; prior to this case, have you worked on a
case involving bacteria as a contaminant of concern?
A No.

11. Dr. Johnson does not understand the basic physical processes of chemical (including phosphorus) adsorption that he is claiming controls the IRW water quality data and his interpretation of the PCA. Dr. Johnson does not know the correct form and formula for phosphorus in water; he does not understand basic adsorption properties of negatively changed anions and negatively charged particles; he does understand the partition coefficient that controls phosphorus adsorption; he does not know the effects of pH on adsorption; he does not know the surface charge of the suspended particles at the pH values of the waters of the IRW; and he does not know levels that result in muddy and salty waters. In summary, Dr. Johnson does not understand the basic principles of the geochemical processes that he opines are controlling water quality data in the IRW. This is illustrated by the following questions and responses in Dr. Johnson's deposition.

445
Q Do you know the value of the partition 01:34PM

446
coefficient for dissolved phosphorus in the IRW
streams?
A No, I don't.
Q Would that have been important to
demonstrating your analysis that's represented in 01:34PM
Figure 4-7?
A It would not have changed the empirical

observation. The total phosphorus, total iron and
total aluminum increased in samples along that
trend. 01:34PM
Q But you will agree, will you not, that the
partition coefficient is a method to explain what
you're demonstrating in Figure 4-7?
A If I wanted to make a predictive model instead
of an -- instead of evaluate the results of an 01:34PM
empirical model, I would use a partition
coefficient, given certain other parameters, to
predict if phosphorus would be in a dissolved phase
versus associated with particulate phase.
Q Can you tell me what form phosphorus is found 01:35PM
in the IRW rivers?
MR. GEORGE: Object to form.
A It has been -- there are analyses for both
total phosphorus and dissolved -- and -- total
phosphorus and dissolved phosphorus. 01:35PM

447

Q What about for dissolved phosphorus; what form
is it in?
A The two that are in SW3 are dissolved
phosphorus and soluble reactive phosphorus. I think
that's considered a soluble phosphorus as well. 01:35PM
Q You want to look that up?
A I'm sorry?
Q Do you want to look that up to be sure?
A No.
Q Okay. I'm going to hand you a blank page 01:35PM
marked as Exhibit 23.
MR. GEORGE: Can I get my page?
MR. PAGE: Do you want one?
MR. GEORGE: I'll do without.

447

Q Would you please write the chemical formula 01:36PM
for the form of phosphorus, dissolved phosphorus
found in the IRW rivers?
A I'm not sure I know the chemical formula for
that form of phosphorus. I don't know if it's
associated with phosphate or whether it's 01:36PM
three-phase.
Q Would you write both of them for us, please?
A I don't know the -- I don't know exactly what

it is -- I don't know exactly what form it is
associated with. 01:36PM

448

Q Would you write the formula for phosphates,
sir?
A (Witness complied).
Q Would you put the charge on the formula,
please? 01:36PM
A I don't recall the valence of the phosphate
cat -- anion.
Q Well, if it's dissolved, what would you expect
it to be?
A I would expect it to be negative. I would 01:37PM
expect it -- my recollection is perhaps minus 2 but
it might be minus 3 or minus 4. I don't recall.
Q Okay. Could you just kind of put -- indicate
what you think the range is for phosphate.
A I put minus 2 to minus 3, and that's my 01:37PM
recollection.
Q Fair enough, and can you tell me what are the
suspended particles that adsorb the P?
A The reference that I cite indicates aluminum,
manganese, hydroxides. The degree to which they are 01:37PM
also adsorbed by clay particles. I don't know.

449

Q Okay. Would they be negatively or positively
charged?
A Well, the iron hydroxide, I think, would be
electrically neutral because it would have both the 01:38PM
cation and the anion.
Q What about aluminum?
A I would think the same thing.
Q Neutral?
A The aluminum plus the hydroxide, I don't know 01:38PM
if there's an anionic complex that would still have
aluminum or iron associated with it that would have
a negative valence but --
Q If these are suspended particulates, would you
expect them to be negative or positively charged? 01:38PM
A I don't know.
Q Do you understand how adsorption is affected
by the pH in the water of the IRW?
A I know that pH exerts a control over which the

degree -- the degree to which these analytes would 01:39PM
be adsorbed to particulates that would be in
solution. Exactly what pH would cause a phosphate
ion to go into solution or be adsorbed, I could not
tell you.

450

Q If pH was between 7.3 and 7.8, would the
surface charge of the aluminum silicates, iron
oxides and clays be all negatively charged? 01:40PM

451

MR. GEORGE: Object to form.
A I don't know.
Q Is it your understanding, sir, that negatively
charged constituents or species repel each other?
A Yes.

451

Q Well, if the phosphorus is in a dissolved
phase and it's negatively charged and the 01:41PM
particulates are also negatively charged, would you
expect adsorption to occur?
MS. COLLINS: Object to form.
A I don't know. I've not approached this from a
kinetics standpoint. There are others on our team 01:41PM
that did.

12. On pg 447, lines 18 - 21, Dr. Johnson states: "I'm not sure I know the chemical formula for that form of phosphorus. I don't know if it's associated with phosphate or whether it's three-phase." The phrase "three-phase" is a typographical error and should be "free-phase". By "free-phase", Dr. Johnson is referring to elemental phosphorus. Apparently Dr. Johnson is unaware that elemental phosphorus does not exist in the environment. Dr. Johnson does not know the magnitude of the negative charge on phosphate and does not know that the chemical formula and magnitude of the charge changes with the pH values of the water. Dr. Johnson does not know that the major adsorption media in the IRW waters are suspended fine-grained clay

particles. Dr. Johnson does not know that at the pH values of the IRW waters, that the suspended clay particles will have a negatively charged surface. Dr. Johnson does not know the basic processes and the pH values that control the surface charges on suspended particles. Dr. Johnson does not understand that the dissolved phosphate anions (negatively charged species) will not readily adsorb to the clay particles (like charge repel). Dr. Johnson does not know that a partition coefficient is a value that provides the amount of a chemical (e.g., phosphate) in dissolved and adsorbed phases at equilibrium conditions. He mistakenly thought that the partition coefficient was a kinetic parameter not an equilibrium parameter. Dr. Johnson also does not know that the IRW waters and collected samples are not "salty". Dr. Johnson also does not understand that the vast majority of waters collected in the IRW had low total suspended sediment concentrations and were in fact clear and not "muddy". In summary, Dr. Johnson does not understand the basic geochemical processes that he opines are the controlling processes in the IRW waters. Without this basic knowledge and understanding, Dr. Johnson has no scientific basis for his opinion.

13. In addition to Dr. Johnson's lack of understanding of his proposed controlling processes, Dr. Johnson's opinion that the physical adsorption processes that result in phosphorus bound to particulate are dominant in the IRW has no factual basis. His opinion does not fit or agree with the observed facts (i.e., the measured phosphorus concentrations in the IRW waters). For Dr. Johnson's opinion to be accurate, he must conclude that most of the phosphorus in the IRW waters is adsorbed ("bound") to the particulates (suspended sediments) and that little phosphorus is in the dissolved form. In his deposition, Dr. Johnson wrongly stated that this is the case many times:

144

Q So it's your opinion that most of the phosphorus that runs off from land-applied fields where poultry waste has been applied is in the particulate form? 01:46PM

MR. GEORGE: Object to form.

A I'm saying most of the total phosphorus that we measure in the water is bound to particulates.

148

A ....

....

. -- that doesn't change the basic conclusion that total phosphorus prefers -- tends to be associated with the particulate phase. I don't need to take that -- I don't need to take that next step to back up a conclusion that total phosphorus tends to be associated with the -- with sediments. 01:51PM 01:52PM

149

Q I'm trying to understand, Doctor. Wouldn't that information be helpful for you in determining whether or not this is a source-driven versus a process-driven system?

MR. GEORGE: Object to form. 01:53PM

A No.

MR. GEORGE: Asked and answered.

Q Why not?

A It is a process -- first order this is a process-driven system because the first order to 01:54PM

150

trends on the first two principal components are driven by iron and aluminum, which is a surrogate for particulates on one trend and sodium, potassium, the more soluble analytes, on the other trend.

151

A Phosphorus, regardless of source or regardless whether, as you suggested perhaps, some background level, total phosphorus will -- has an affinity for the particulate phase, and that's what we're see -- that's what is driving this analysis. 01:56PM

444

A So the total phosphorus -- total phosphorus is 01:32PM

445

-- has -- a large part of the control in whatever
total phosphorus you find, based on this, leads me
to conclude it's related to adsorption to
particulate matter, which is preferentially going to
be iron and aluminum.

454

Q But if you were really trying to understand
whether or not particulates or this iron and
aluminum and clays, let's say, particulates were in 01:47PM

455

fact driving PC1, wouldn't it be important to also
know whether or not they're having an impact on
dissolved phase constituents in the same samples?
A I could look at that data to determine if it
was consistent, but I would -- but I had literature 01:47PM
and I had data that was not included in the PCA that
were supportive of my conclusion that total
phosphorus was a function of iron, aluminum and
total suspended solids. You're asking are there
other things that I could have looked at to see if 01:47PM
that was also consistent with that, yes, there
probably were, and this may well be one of them, but
I did not do that part of it if that's what you're
asking.

14. In the above statements, Dr. Johnson ignores both the site specific literature concerning the IRW and the data collected in the IRW (over 2,000 phosphorus measurements in surface water) that show that most of the phosphorus in the IRW surface waters is in the dissolved form and not adsorbed to particulates. During his deposition, portions of a peered-reviewed article concerning research in the IRW (P. Moore et al., 1998, Decreasing Metal Runoff from Poultry Litter with Aluminum Sulfate, J. Environ. Qual., Vol 27, pages 92-99: attached as Johnson Deposition Exhibit 6) were read by Dr. Johnson:

175

A The majority, 80 to 90 percent, of the P in runoff from fields fertilized with poultry litter is dissolved P, which is the form most readily available to algae.

Q Would you agree or disagree with the last statement you read there that says the majority, 80 to 90 percent, of P in runoff water from fields fertilized with poultry litter is dissolved P, which is the form most readily available to algae? 02:46PM

MR. GEORGE: Object to form. 02:46PM

A I don't know. I don't -- I have no reason to disagree with these guys.

Q Do you have any understanding of what the -- did you do any study of what the most common form of P is that is running off from poultry-litter applied 02:46PM

176

fields, whether it's dissolved or total or particulate P?

MR. GEORGE: Object to form, asked and answered.

A No.

15. Understanding the amounts of dissolved and particulate phosphorus actually observed in the IRW surface waters is necessary to validate Dr. Johnson's opinion that geochemical partitioning is controlling the water quality data. Because Dr. Johnson lacks this understanding and ignores the actual water quality data collected in the IRW, his opinion has no basis and is wrong.

16. Dr. Johnson has characterized his process controlled systems as simply muddy and salty waters. That is, if particulate or suspended materials control the system and PC1 (associated with poultry waste), the waters are "muddy". If total dissolved solids control PC2 (associated with WWTP discharges), then the waters are "salty". However, Dr. Johnson was not able to quantify the terms "muddy" and "salty" as shown in the following responses. In addition, Dr. Johnson's opinion that most of the phosphorus is associated with suspended material or

particulates can easily be shown to be inaccurate and without factual basis by evaluating the observed data and comparing the amounts of the particulate phosphorus and dissolved phosphorus in actual samples collected from the IRW and analyzed in laboratories. "Total phosphorus" reported by the laboratories measures both the particulate bound and dissolved phosphorus and "total dissolved phosphorus" measures only the dissolved phosphorus. In the following questions and responses, Dr. Johnson was asked to compare the levels of total suspended solids, total phosphorus and total dissolved phosphorus concentrations for the various types of IRW samples collected by the USGS and the plaintiffs. Looking at Appendix C of Olsen Expert Report, page 2 of exhibit 24 of Dr. Johnson's deposition (attached), Table 1, Summary of Edge Field Poultry Samples, Dr. Johnson had the following responses to questions.

456

Q Would you look at the total suspended and
total dissolved solids, sir, under average?
A The highlighted section?
Q Yes, sir.
A Okay. I'm looking at it. 01:49PM

457

Q Okay. What is the total dissolved solids?
A 405.25.
Q And total suspended solids are what level?
A 267.984.
Q With regard to the total suspended solids, 01:49PM
would you characterize those as being the -- I'm
going to use it loosely -- but the muddy
characterization?
A Yes, using that term loosely.
Q You would say --
A The higher total suspended solids implies
higher turbidity, which would be characterized as
muddier.
Q And would you be able to tell if this water --
would this water appear muddy or clear at 267.984 01:50PM
TSS?

A I don't know visually how that number would compare. I don't know how that number would compare to a visual observation of the sample.

458

Q Okay. What about in your total dissolved solids; would that be within the area of salty in your analysis?
A Well, going back to -- okay. The top bin for total sodium plus potassium plus chloride plus sulfate -- well, that's -- there's more to total dissolved solids than just those four, but those on their own, the top bin of this graph is greater than 300 milligrams per liter. So this 405, to the extent that total dissolved solids can be taken -- that these four analytes can be taken as a proxy for total dissolved solid, this looks to be on the high end of the range. 01:51PM 01:52PM
Q Okay. Can I ask you, sir, to look at the total P using method 4500 and using total dissolved total P using 4500, and could you give me those two averages, please? 01:52PM
A You want me to average the two values?
Q Well, I think the average values are provided for you there. 01:52PM
A Oh, I see. Total dissolved P by 4500 PF is 4.8239. Total phosphorus by 4500 PF is 8.1395.
Q So what would be -- would the approximate dissolved phase of phosphorus be equal to about 59 percent of the total phosphorus in this particular 01:53PM

459

sample, on these edge of field samples?
MR. GEORGE: You're referring to the average, David?
MR. PAGE: Yes.
A It appears to be greater than half. So 59, I would have no reason to question that number. 01:53PM
Q Given that level of dissolved phase phosphorus, would that indicate that at least leaving the fields, there's still a substantial amount of dissolved phosphorus in the system? 01:53PM
MR. GEORGE: Object to form.
A I'm sorry. I didn't -- I faded on the

question. Could you --
Q I apologize. I probably faded when I --
(Whereupon, the court reporter read 01:53PM
back the previous question.)
A Well, to the extent that these edge of fields represent what is truly leaving a field. I know there are some people on our side that have -- that have questions about whether or not that's 01:54PM representative of the water leaving the field, but taking that at face value, yes.
Q Are you going to be giving any testimony about what is and what isn't representative in the edge of field samples? 01:54PM

460

A I will not.

460

Q Well, if I would have just said to you, sir, 01:55PM

461

rather than -- that there's -- this data indicates there's a large component of dissolved phase in edge of field samples that are in Dr. Olsen's report, would you feel better about answering that question?
A Yes, absolutely. 01:55PM
Q Okay. Thank you. So your answer is yes to my question?
A To that question, yes.

16. Looking at Appendix C of Olsen Expert Report, page 4 of Exhibit 24, Table 3, Summary of Small Tributary Samples - Base Flow Conditions, Dr. Johnson had the following responses to questions:

461

Q Okay, and what's the total suspended solids average value for those types of samples? 01:56PM

462

A 6.8958.
Q At that level of TSS, would you expect there to be sufficient particulates to create an adsorption of phosphorus?

MR. GEORGE: Object to form. 01:56PM
A Well, there are particulates where it wouldn't -- where it would be zero. Total suspended solids does not equal zero.
Q Right, but would you tend to believe that where you have TSS at 6 -- let's say 7 milligrams 01:57PM per liter, that there would be sufficient particulates to affect an adsorption phenomena that you're claiming is occurring in PC1 between the particulates and phosphorus?
MR. GEORGE: Object to form. 01:57PM
A To the extent that there are suspended solids in the samples that contributed to this average, I don't think -- even if they're a relatively low concentration, it would not be my understanding that because there's a lower concentration of total 01:57PM suspended solids that they were somehow exempt from the processes of adsorption and desorption.
Q And what was the average pH for the base flow samples?
A pH? 01:58PM

463

Q Yes.
A Is that highlighted or is this someplace else in the table?
Q It's at the bottom line. I don't believe I've highlighted this one. 01:58PM
A Oh. 7.4673.
Q And would that be a pH that would create an affinity for adsorption between particles and dissolved fraction of phosphorus?
A I don't know. 01:58PM
Q Okay. How much phosphorus can 7 milligrams per liter of TSS adsorb?
A I don't -- I couldn't give you a number.
Q Okay. Would you take a look at the total dissolved phosphorus under 4500 method and total 01:58PM phosphorus for 4500 and give me -- and read those for the Record, please.
A Total dissolved phosphorus, 2.873.
Q Excuse me. Did you mean to say .2873?
A Yes, I did. I'm sorry if I did not say that. 01:59PM 0.2873.
Q Okay, and what about total phosphorus?

A 0.337.
Q Would that -- would the dissolved-to-total phosphorus fraction be about 85 percent in these 01:59PM

464

stream samples on average?
A Comparing those numbers, that seems about right.
Q So there's a substantial amount of dissolved phase phosphorus in base flow stream samples that 01:59PM were collected in the IRW; is that correct?
A Appears so, to the extent that these averages are representative of the dataset as a whole.

17. Looking at Appendix C of Olsen Expert report, page 6 of Exhibit 24, Table 4, Summary of Small Tributary Samples - High Flow Conditions, Dr. Johnson had the following responses to questions:

465

Q Okay. What's the TSS level, average level for this particular -- 02:19PM
A 11 --
Q -- group of samples?
A I'm sorry. Are you finished? 11.2712.
Q Would you consider that a low TSS number?
A Within the ranges of the data in SW3, I would 02:20PM call it moderate. It's not -- on this figure that I have, 4-8, it's colored. That would end up being plotted as a green symbol, which would be in the middle of the range.
Q From your perspective of your knowledge of TSS 02:21PM levels in ambient waters, would you consider that a high TSS level?
A I'm not familiar with how total suspended solids in other watersheds would compare with the data we're seeing here. I don't know if it would be 02:21PM considered high or low.
Q Really? Would you consider that to be a sufficient TSS to be a muddy water?
A Again, I would echo the answers that I gave with response to any specific value, and I'd be glad 02:21PM

466

to go through that whole soliloquy again, but I indicated that there is no threshold where we cross the boundary from not muddy to muddy. This would fall along that continuum.
Q Would you consider these waters appear to be clear based on your experience? 02:21PM
A It's closer to the bottom of the TSS range than it is to the top.

467

Q Would you read for the Record the dissolved P method 4500 and the total phosphorus at the 4500?
A You mean the average concentrations for those two?
Q Yes, sir. I'm just going to focus on average concentration for this line of questions. 02:23PM
A Total dissolved P by 4500 PF, 0.2932. Total P by 4500 PF, 0.3117.
Q Would you estimate that the fraction of dissolved P would be greater than 90 percent in these samples? 02:23PM
A Around 90 looks to be a reasonable estimate.
Q Wouldn't that tend to negate your hypothesis that there's an affinity of phosphorus for total suspended solids in this system? 02:24PM

468

MR. GEORGE: Object to form.
A You previously -- this means that, if I'm reading this data correctly, the majority of the phosphorus in these samples is total dissolved.
Q Yes. 02:24PM
A And we have total suspended solids, which is on the low end. So I think this would be consistent with what I concluded in -- the samples to the left side of this graph tend to have lower total phosphate and -- I'm not sure I understand the question. 02:24PM
Q Well, doesn't this indicate, sir, that there isn't a lot of adsorption going on in small tributaries during high flow conditions?
MR. GEORGE: Object to form. 02:25PM
A We have both low total phosphate and we have relatively low total suspended solids. So for

samples within that range of total suspended solids,
I would agree with that.

18. Looking at Appendix C of Olsen Expert Report, page 8 of Exhibit 24, Table 5, Summary of Surface Water/Rivers Base Flow, Dr. Johnson had the following responses to questions:

471

Q Okay, and, again, could you tell the court what the total suspended solids level is? 02:28PM
MR. GEORGE: The average?
MR. PAGE: Yes, the average.
A Average of 124 samples, 5.0161.
Q Okay, and could you again for my benefit read the total fraction or total phosphorus under 4500 02:28PM method and then the dissolved fraction?
A Total P, 0.1466; total dissolved P, 0.1183.
Q Okay. Would that be approximately 80 percent dissolved fraction of all the phosphorus that's represented by these samples? 02:28PM
A 80 percent looks like a good estimate.
Q Does the level of total suspended solids indicate that there would be very little adsorption of dissolved phosphorus in samples of the type that are represented on Page 8? 02:29PM
MR. GEORGE: Object to form.
A Yes, compared to dissolved.

19. Looking At Appendix C of Olsen Expert Report, page 10 of Exhibit 24, Table 6, Summary of Surface Water/Rivers High Flow, Dr. Johnson had the following responses to questions:

472

Q What's the TSS average shown on Page 10 for rivers high flow? 02:30PM
A 15.25 milligrams per liter.
Q Would you consider that a level of TSS that would be -- cause the waters to be cloudy?
A Again, same answer as previously. It falls within -- the range of my Figure 4-8, a sample of 02:30PM

473

that TSS would be plotted green, which is moderate in terms of that range of values from low to high TSS. I don't know if visually that would end up being a cloudy sample or not.

Q You don't know whether you could see 15.25 milligrams per liter TSS in a water sample? 02:31PM

A No, I don't.

Q Would you again for me, sir, identify the averages for total P and total dissolved P for methods 4500? 02:31PM

A Total P, 0.1186; total dissolved P, 0.0855.

Q Does that appear that the dissolved fraction is about 75 percent of the total fraction?

A It seems like a good estimate.

Q Does that appear that there's little adsorption going on in these samples? 02:31PM

MR. GEORGE: Object to form.

A Appears that the majority would be in the dissolved phase.

Q So there's not much of an affinity -- would you believe there's not much of an affinity between the phosphorus and TS -- excuse me -- total suspended solids -- 02:32PM

A I think it indicates the majority is in the dissolved phase. I would not say that what 02:32PM

474

particulates are there would not show an affinity for phosphorus. It's just that there are low concentrations of suspended solids.

Q Are there sufficient TSS or suspended solids to transform the total dissolved phosphorus into particulate phase? 02:32PM

A No. The majority here is still total dissolved.

472

Q What's the TSS average shown on Page 10 for rivers high flow? 02:30PM

A 15.25 milligrams per liter.

Q Would you consider that a level of TSS that would be -- cause the waters to be cloudy?

A Again, same answer as previously. It falls within -- the range of my Figure 4-8, a sample of 02:30PM

473

that TSS would be plotted green, which is moderate in terms of that range of values from low to high TSS. I don't know if visually that would end up being a cloudy sample or not.
Q You don't know whether you could see 15.25 02:31PM milligrams per liter TSS in a water sample?
A No, I don't.
Q Would you again for me, sir, identify the averages for total P and total dissolved P for methods 4500? 02:31PM
A Total P, 0.1186; total dissolved P, 0.0855.
Q Does that appear that the dissolved fraction is about 75 percent of the total fraction?
A It seems like a good estimate.
Q Does that appear that there's little 02:31PM adsorption going on in these samples?
MR. GEORGE: Object to form.
A Appears that the majority would be in the dissolved phase.
Q So there's not much of an affinity -- would 02:32PM you believe there's not much of an affinity between the phosphorus and TS -- excuse me -- total suspended solids --
A I think it indicates the majority is in the dissolved phase. I would not say that what 02:32PM

474

particulates are there would not show an affinity for phosphorus. It's just that there are low concentrations of suspended solids.
Q Are there sufficient TSS or suspended solids to transform the total dissolved phosphorus into 02:32PM particulate phase?
A No. The majority here is still total dissolved.

20. Looking at Appendix C of Olsen Expert Report, Page 12 of Exhibit 24, Table 7, Summary of USGS Sampling Base Flow, Dr. Johnson had the following responses to questions:

474

Q Okay. What's the total suspended solids 02:33PM

475

concentrations average shown by the USGS samples for
base flow?
A Well, this one is listed as suspended sediment
concentration rather than total suspended solids.
I'm not sure if that means it's a completely 02:33PM
different analyte or not, but the number is 7.5532
milligrams per liter.

477

Q All right, and would you please tell the court
what the total phosphorus values are, average values 02:36PM
for this dataset and the dissolved phosphorus?
A Total phosphorus, 0.163. Dissolved phosphorus
is 0.1573, both units -- units for both milligrams
per liter.
Q Does that appear to you, sir, to be about 90 02:36PM
percent of the phosphorus in this dataset to be in
the --
A That looks to be a reasonable estimate.
Q -- in the dissolved phase?
A I'm sorry. I'm anticipating your questions. 02:36PM
Sorry.
Q After a couple of times --
A It's probably safe.
Q Does this TSS data and the dissolved phase
data indicate that there's much affinity between the 02:37PM
TSS and the phosphorus that's in these samples?
A It tells me that most of the samples appears
to be in the dissolved phase and the TSS is low, so
that's where -- the majority of the phosphorus
that's in this system is in solution. 02:37PM

478

Q So in these particular samples, you wouldn't
be expected to find the adsorption process that you
discuss in your expert report; is that correct?
MR. GEORGE: Object to form.
A Well, I would expect to find adsorption. I 02:37PM
don't think we could avoid adsorption. I think it's
less than we would find in a highly turbid or high
TSS sample, higher TSS sample.
Q But it wouldn't be the dominant process for
these samples; correct? 02:37PM
A No, correct.

21. Looking at Appendix C of Olsen Expert Report, page 15 of Exhibit 24, Table 8, Summary of USGS Sampling High Flow Samples, Dr. Johnson had the following responses to questions:

478

Q Yes, sir. Okay. In this dataset, what is the
TSS average?
MR. GEORGE: By TSS, you are referring to
suspended sediment? 02:38PM
A Concentration --
Q Yes. I think we assumed that.
A That was my assumption. 1 -- 130.769
milligrams per liter.

479

Q Would you please identify the total and 02:39PM
dissolved phosphorus results, average results for
this dataset?
A Average results here, we're looking at about
93 samples. Average for total phosphorus, 0.1756
milligrams per liter; dissolved phosphorus, 0.1082 02:39PM
milligrams her liter.
Q And did you find that to be about 60 percent?
A Again, your percentages seem to be reasonable
estimates across the board.

481

Q Well, it would be on Page 16, the average pH
levels. What's the average pH for these samples
sir? 02:43PM
A Average pH on Page 16 for USGS high flow
samples is 7.6346.
Q And what's the range for all that set of
samples?
A 6.2 to 8.8. 02:43PM

482

Q Basically in your understanding of adsorption
principles would you expect there would be more
affinity or less affinity for adsorption of pH
levels at that rate?

MR. GEORGE: Object to form. 02:43PM
A I'm not sure. I understand that pH of the water is important to adsorption and desorption. At what point one process is favored over another as a function of pH, I can't tell you.
Q Can you tell us whether or not 8.8 would represent less adsorption, all other things being equal in a system, versus 6.2 pH? 02:43PM
A Not with confidence, no.

22. Looking at Appendix C of Olsen Expert Report, page 20 of Exhibit 24, Table 10, Summary of Reference Samples Base Flow, Dr. Johnson had the following responses to questions:

482

Q Can you tell us what the total suspended solids are in the reference streams?
A The average is 2.7143.
Q And what's the range? 02:44PM
A One to six.
Q So would you characterize that as low TSS?
A Yes. Looking back through the tables we've gone through thus far, that's the lowest number we've had. 02:45PM

483

Q Would you know whether or not that water at that TSS level would appear cloudy or not?
A I would expect it not to appear cloudy.
Q You're not sure about 7 TDS, but you are confident that when it gets down to 2.7, it would not appear cloudy? 02:45PM
A I would expect a TSS of 2.7 to plot on the left -- the far left side of this graph, and that leads me to suspect that that sample, being at the far end of that continuum, would -- I would be surprised if it was not clear. 02:45PM
Q Would you tell us what the total dissolved phosphorus is under method 4500 versus the total phosphorus?
A Total dissolved phosphorus is 0.0072. 02:46PM
Q All right, and what about total phosphorus?
A Total phosphorus is 0.0138.

Q Does that indicate that the dissolved fraction is around 50 percent?
A Yes. 02:46PM
Q Dr. Johnson, how do these phosphorus levels compare to the phosphorus levels from the other groups of samples we've just reviewed?
MR. GEORGE: All groups, David?
MR. PAGE: Sure. 02:46PM

484

MR. GEORGE: Object to form.
A Looks to be the lowest of the ones we've discussed so far.
Q Would you do the same -- the same comparison for total suspended solids also, sir? 02:47PM
A Didn't we already do that?
Q I want you to compare -- I think we did look -- I compared the USGS. Did you take a review of all of them recently?
A For total suspended solids, I thought I did. 02:47PM Maybe you're thinking back to USGS.
Q Okay. If I misunderstood you, I apologize.
A Yes. It looks to be below total suspended solids.
Q And would you do the same evaluation for total 02:48PM suspended solids, sir?
A Unless I missed a page, it appears to be lowest.
Q And would the highest be the edge of field samples? 02:48PM
A For total dissolved?
Q And total suspended if you want to look at the same time, please.
A Yes. It appears to be highest in edge of field. 02:49PM

485

Q You've been referencing your trend analysis. How many samples did you look at when you did your trend analysis and you evaluated the affinity between phosphorus and these --
MR. GEORGE: Objection, asked and answered. 02:49PM
MR. PAGE: I haven't even finished the question yet.
MR. GEORGE: Well, it's already been asked

and answered. So you can ask it another time if you
want to. 02:49PM
Q How many samples did you evaluate for your bottom trend when you did your analysis of affinity between phosphorus and particulates?
MR. GEORGE: Same objection.
A Within my report, there would have been the five bar graphs where I showed all the analytes. 02:50PM
Q Five samples; correct?
A Correct.
Q And the analysis that we just went through includes 2,000 samples, that is, in Appendix C, does it not? 02:50PM
A That's correct.

23. The above questions and responses show that the waters of the IRW have low total dissolved solids and are not salty. The questions and responses show that the vast majority of IRW waters have very low total suspended solids and are not muddy. The questions and responses show that in all cases, the majority of the phosphorus is dissolved and not associated with the suspended particulates as opined by Dr. Johnson. As a result, Dr. Johnson has no factual basis for his opinion concerning the controlling processes (total concentrations and geochemical partitioning) in the IRW that supposedly drive the PCA and control water quality data. His opinions concerning these matters do not fit or agree with the actual observed surface water quality data for the IRW.

I declare under penalty of perjury, under the laws of the United States of America, that the foregoing is true and correct.

Executed on the 15th day of May, 2009.

Roger L. Olsen

Roger L. Olsen, Ph.D.

$PO_4^{-2 \text{ to } -3}$

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Appendix C : Water
Table 1: Summary of Edge of Field Poultry Samples

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	64	5	2120	112.25	263.2598	mg/L	63/64 (98%)
Campylobacter species	60	0.5	1	0.8	0.247	MPN*/100ml	0/60 (0%)
E. coli	65	17	1600000	89669	270511.02	MPN*/100ml	65/65 (100%)
Enterococcus Group	65	110	1600000	125623	323571.71	MPN*/100ml	65/65 (100%)
Fecal Coliform	68	30	1600000	89894.2	266805.66	MPN*/100ml	68/68 (100%)
Salmonella species	68	0.5	46	2.2721	6.1677	MPN*/100ml	10/68 (15%)
Staphylococcus aureus	68	0.55	488	11.2351	63.064	MPN*/100ml	9/68 (13%)
Total Coliform	68	200	1600000	220466	422114.21	MPN*/100ml	68/68 (100%)
Chloride	64	0.5	806	22.4577	100.5138	mg/L	60/64 (94%)
17a-estradiol	42	0.5	25.5	3.2812	4.9017	ng/L	3/42 (7%)
17b-estradiol	42	0.5	25.5	2.941	4.1839	ng/L	2/42 (5%)
Estriol	42	0.5	449	13.756	68.9556	ng/L	3/42 (7%)
Estrone	42	0.5	108	7.6674	18.6267	ng/L	7/42 (17%)
Dissolved Aluminum	82	0.05	5	0.3284	0.6627	mg/L	44/82 (54%)
Dissolved Antimony	82	0.0005	0.05	0.004	0.0066	mg/L	3/82 (4%)
Dissolved Arsenic	90	0.0005	72.6	0.8156	7.6518	mg/L	39/90 (43%)
Dissolved Barium	82	0.005	0.312	0.0594	0.0586	mg/L	80/82 (98%)
Dissolved Beryllium	82	0.0005	0.05	0.0012	0.0055	mg/L	0/82 (0%)
Dissolved Boron	1	0.021	0.021	0.021		mg/L	1/1 (100%)
Dissolved Cadmium	82	0.0005	0.05	0.0019	0.0064	mg/L	2/82 (2%)
Dissolved Calcium	82	4.224	285.186	37.3636	44.3506	mg/L	82/82 (100%)
Dissolved Chromium	82	0.0005	0.499	0.0082	0.0549	mg/L	15/82 (18%)
Dissolved Cobalt	82	0.0005	7.2	0.1511	0.9476	mg/L	45/82 (55%)
Dissolved Copper	90	0.001	5.08	0.1244	0.5455	mg/L	78/90 (87%)
Dissolved Iron	82	0.05	20.8	0.6148	2.3351	mg/L	57/82 (70%)
Dissolved Lead	82	0.0005	0.05	0.0028	0.0058	mg/L	8/82 (10%)
Dissolved Magnesium	82	0.506	171	6.233	19.0908	mg/L	82/82 (100%)
Dissolved Manganese	82	0.002	2.898	0.2651	0.5229	mg/L	75/82 (91%)
Dissolved Mercury	80	0.0001	0.0004	0.0001	0	mg/L	3/80 (4%)
Dissolved Molybdenum	68	0.0005	0.25	0.0162	0.0309	mg/L	12/68 (18%)
Dissolved Nickel	82	0.0005	0.538	0.0129	0.0592	mg/L	46/82 (56%)
Dissolved Potassium	82	0.005	1960	42.6502	216.3475	mg/L	79/82 (96%)
Dissolved Selenium	82	0.0005	0.05	0.0039	0.0066	mg/L	5/82 (6%)
Dissolved Silver	82	0.0005	0.05	0.0024	0.0057	mg/L	1/82 (1%)
Dissolved Sodium	82	0.485	800	19.7744	88.8618	mg/L	81/82 (99%)
Dissolved Strontium	1	0.0005	0.0005	0.0005		mg/L	0/1 (0%)
Dissolved Thallium	82	0.0005	0.05	0.0068	0.0097	mg/L	0/82 (0%)
Dissolved Titanium	1	0.0005	0.0005	0.0005		mg/L	0/1 (0%)
Dissolved Vanadium	82	0.0005	0.5	0.012	0.0549	mg/L	2/82 (2%)
Dissolved Zinc	90	0.0025	4.16	0.0823	0.4382	mg/L	64/90 (71%)
Total Aluminum	82	0.05	141.307	9.4983	18.1173	mg/L	77/82 (94%)
Total Antimony	82	0.0005	0.05	0.0037	0.0061	mg/L	2/82 (2%)
Total Arsenic	90	0.0005	0.698	0.0196	0.077	mg/L	57/90 (63%)
Total Barium	82	0.01	4.178	0.1863	0.472	mg/L	81/82 (99%)
Total Beryllium	82	0.0005	0.05	0.0015	0.0056	mg/L	14/82 (17%)
Total Cadmium	82	0.0005	0.05	0.0015	0.0055	mg/L	1/82 (1%)
Total Calcium	82	4.559	1150	64.8345	146.8496	mg/L	82/82 (100%)
Total Chromium	82	0.0005	0.491	0.0222	0.0585	mg/L	60/82 (73%)
Total Cobalt	82	0.0005	0.156	0.01	0.0206	mg/L	39/82 (48%)
Total Copper	90	0.0005	4.36	0.1799	0.5672	mg/L	84/90 (93%)
Total Iron	82	0.217	152.363	12.1774	21.1138	mg/L	82/82 (100%)
Total Lead	82	0.0005	0.246	0.0178	0.0344	mg/L	57/82 (70%)
Total Magnesium	82	0.974	159	7.1483	17.9954	mg/L	82/82 (100%)
Total Manganese	82	0.009	9.878	0.692	1.3941	mg/L	82/82 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C : Water
Table 1: Summary of Edge of Field Poultry Samples

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Mercury	82	0.0001	0.0005	0.0001	0.0001	mg/L	2/82 (2%)
Total Molybdenum	55	0.001	0.031	0.0044	0.0058	mg/L	14/55 (25%)
Total Nickel	82	0.001	0.527	0.0188	0.0592	mg/L	73/82 (89%)
Total Potassium	82	2.3	1900	47.9513	210.2446	mg/L	82/82 (100%)
Total Selenium	82	0.0005	0.05	0.0036	0.0061	mg/L	5/82 (6%)
Total Silver	82	0.0005	0.05	0.0023	0.0056	mg/L	0/82 (0%)
Total Sodium	82	0.413	799	19.868	88.8605	mg/L	82/82 (100%)
Total Thallium	82	0.0005	0.05	0.0063	0.0084	mg/L	0/82 (0%)
Total Vanadium	82	0.0005	0.5	0.0297	0.0672	mg/L	40/82 (49%)
Total Zinc	90	0.0025	3.35	0.1646	0.4218	mg/L	85/90 (94%)
Ammonia Nitrogen	64	0.05	183	4.2337	22.9529	mg/L	53/64 (83%)
Nitrite + Nitrate (as N)	66	0.05	7.61	1.5568	1.5522	mg/L	55/66 (83%)
Total Kjeldahl Nitrogen	76	0.3	681	24.3989	84.8912	mg/L	73/76 (96%)
Brevibacteria 16S rRNA	38	2613.120	55638130	8502780	18164465	Copies/L	21/38 (55%)
Dissolved Ortho P (365.2)	36	0.0125	4.326	0.2971	0.7906	mg/L	19/36 (53%)
Soluble Reactive P (4500PF)	42	0.0179	60	3.7517	9.8547	mg/L	42/42 (100%)
Total Dissolved P (365.2)	39	0.0125	6.18	0.5554	1.1863	mg/L	32/39 (82%)
Total Dissolved P (4500PF)	42	0.024	93.7	4.8239	14.8433	mg/L	42/42 (100%)
Total Dissolved P (6010)	48	0.093	23.988	1.8334	3.6525	mg/L	48/48 (100%)
Total Dissolved P (6020)	42	0.024	145	6.0349	22.49	mg/L	42/42 (100%)
Total ortho P (365.2)	37	0.041	17.459	2.2967	3.6899	mg/L	35/37 (95%)
Total P (365.2)	39	0.14	23.893	3.6849	5.9234	mg/L	39/39 (100%)
Total P (4500PF)	42	0.074	190	8.1395	29.425	mg/L	42/42 (100%)
Total P (6010)	48	0.44	67.76	5.7696	11.3418	mg/L	48/48 (100%)
Total P (6020)	42	0.075	1520	42.402	234.4892	mg/L	42/42 (100%)
Total Sulfate (SO4)	64	1.42	460	21.3516	57.1835	mg/L	64/64 (100%)
TOC	67	2.47	2800	58.6615	340.5289	mg/L	67/67 (100%)
Total Dissolved Solids	64	41	9720	405.25	1189.6355	mg/L	64/64 (100%)
Total Suspended Solids	63	4	6060	267.984	773.3278	mg/L	63/63 (100%)
Conductivity	43	0.042	0.59	0.2046	0.147	mmhos/cm	43/43 (100%)
pH	64	5.4	8.02	6.8627	0.5999	s.u.	64/64 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

2

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Appendix C: Water
Table 3: Summary of Small Tributary Samples – Base Flow Conditions

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	48	42	378	135.333	74.024	mg/L	48/48 (100%)
Campylobacter species	23	0.335	1	0.725	0.2994	MPN*/100ml	0/23 (0%)
E. coli	33	1	2200	182.091	394.7955	MPN*/100ml	32/33 (97%)
Enterococcus Group	57	0.5	7600	547.939	1096.1535	MPN*/100ml	56/57 (98%)
Fecal Coliform	57	0.5	91000	3013.64	12860.313	MPN*/100ml	56/57 (98%)
Salmonella species	33	1	33	2.3333	5.5603	MPN*/100ml	9/33 (27%)
Staphylococcus aureus	57	0.55	12000	430.149	1881.5937	MPN*/100ml	24/57 (42%)
Total Coliform	57	0.5	70000	4076.15	10910.526	MPN*/100ml	56/57 (98%)
Chloride	48	4.46	71.6	14.8808	14.9643	mg/L	48/48 (100%)
17a-estradiol	41	0.5	25	2.921	7.351	ng/L	2/41 (5%)
17b-estradiol	41	0.5	25	4.3337	7.1529	ng/L	18/41 (44%)
Estriol	41	0.5	3100	130.168	513.7783	ng/L	6/41 (15%)
Estrone	41	0.5	51.5	6.2515	11.3004	ng/L	11/41 (27%)
Dissolved Aluminum	48	0.005	0.085	0.0403	0.0195	mg/L	5/48 (10%)
Dissolved Antimony	48	0.0005	0.005	0.0017	0.002	mg/L	1/48 (2%)
Dissolved Arsenic	48	0.0005	0.005	0.002	0.0019	mg/L	11/48 (23%)
Dissolved Barium	48	0.028	0.082	0.0525	0.0132	mg/L	48/48 (100%)
Dissolved Beryllium	48	0.0005	0.0005	0.0005	0	mg/L	0/48 (0%)
Dissolved Cadmium	48	0.0005	0.003	0.0008	0.0005	mg/L	6/48 (13%)
Dissolved Calcium	48	16.5	84.9	53.3221	16.0071	mg/L	48/48 (100%)
Dissolved Chromium	48	0.0005	0.003	0.0011	0.0009	mg/L	2/48 (4%)
Dissolved Cobalt	48	0.0005	0.276	0.0085	0.0397	mg/L	7/48 (15%)
Dissolved Copper	48	0.0005	0.024	0.0021	0.0035	mg/L	18/48 (38%)
Dissolved Iron	48	0.005	0.058	0.0447	0.0122	mg/L	12/48 (25%)
Dissolved Lead	48	0.0005	0.009	0.0015	0.0016	mg/L	5/48 (10%)
Dissolved Magnesium	48	0.825	7.872	2.5122	1.2925	mg/L	48/48 (100%)
Dissolved Manganese	48	0.0005	0.384	0.0503	0.1014	mg/L	37/48 (77%)
Dissolved Mercury	48	0.0001	0.0001	0.0001	0	mg/L	0/48 (0%)
Dissolved Molybdenum	48	0.0025	0.025	0.0086	0.0101	mg/L	0/48 (0%)
Dissolved Nickel	48	0.0005	0.005	0.0023	0.0019	mg/L	17/48 (35%)
Dissolved Potassium	48	1.05	17.3	4.3114	3.7456	mg/L	48/48 (100%)
Dissolved Selenium	48	0.0005	0.005	0.0017	0.002	mg/L	1/48 (2%)
Dissolved Silver	48	0.0005	0.0025	0.001	0.0009	mg/L	0/48 (0%)
Dissolved Sodium	48	2.41	62.7	10.9912	13.7729	mg/L	48/48 (100%)
Dissolved Thallium	48	0.0005	0.01	0.0031	0.0043	mg/L	0/48 (0%)
Dissolved Vanadium	48	0.0005	0.106	0.0157	0.0269	mg/L	21/48 (44%)
Dissolved Zinc	48	0.0025	0.086	0.0162	0.0175	mg/L	36/48 (75%)
Total Aluminum	48	0.005	0.786	0.1126	0.1659	mg/L	20/48 (42%)
Total Antimony	48	0.0005	0.005	0.0019	0.002	mg/L	4/48 (8%)
Total Arsenic	48	0.0005	0.005	0.0021	0.0019	mg/L	16/48 (33%)
Total Barium	48	0.029	0.097	0.0542	0.0145	mg/L	48/48 (100%)
Total Beryllium	48	0.0005	0.0005	0.0005	0	mg/L	0/48 (0%)
Total Cadmium	48	0.0005	0.001	0.0006	0.0002	mg/L	0/48 (0%)
Total Calcium	48	17.6	82.4	53.1537	14.9744	mg/L	48/48 (100%)
Total Chromium	48	0.0005	0.0025	0.0012	0.0009	mg/L	9/48 (19%)
Total Cobalt	48	0.0005	0.233	0.0065	0.0335	mg/L	1/48 (2%)
Total Copper	48	0.0005	0.003	0.0013	0.0009	mg/L	11/48 (23%)
Total Iron	48	0.005	1.25	0.1836	0.2763	mg/L	24/48 (50%)
Total Lead	48	0.0005	0.003	0.0012	0.0011	mg/L	1/48 (2%)
Total Magnesium	48	0.873	7.9	2.5641	1.2786	mg/L	48/48 (100%)
Total Manganese	48	0.0005	0.608	0.0728	0.1302	mg/L	38/48 (79%)
Total Mercury	48	0.0001	0.0001	0.0001	0	mg/L	0/48 (0%)
Total Molybdenum	48	0.0025	0.0025	0.0025	0	mg/L	0/48 (0%)
Total Nickel	48	0.0005	0.006	0.0016	0.0012	mg/L	17/48 (35%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 3: Summary of Small Tributary Samples – Base Flow Conditions

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Potassium	48	1.19	14	4.3236	3.645	mg/L	48/48 (100%)
Total Selenium	48	0.0005	0.005	0.0017	0.002	mg/L	1/48 (2%)
Total Silver	48	0.0005	0.0025	0.001	0.0009	mg/L	0/48 (0%)
Total Sodium	48	2.43	64.1	11.0305	14.044	mg/L	48/48 (100%)
Total Thallium	48	0.0005	0.01	0.0031	0.0043	mg/L	0/48 (0%)
Total Vanadium	48	0.0005	0.084	0.0134	0.0233	mg/L	12/48 (25%)
Total Zinc	48	0.0025	0.096	0.0112	0.0178	mg/L	20/48 (42%)
Ammonia Nitrogen	37	0.05	3.49	0.1859	0.5621	mg/L	18/37 (49%)
Nitrite + Nitrate (as N)	48	0.05	14.8	2.4936	3.314	mg/L	46/48 (96%)
Total Kjeldahl Nitrogen	46	0.25	7.6	2.087	1.6873	mg/L	40/46 (87%)
Brevibacteria 16S rRNA	12	126000	126000	126000		Copies/L	4/12 (33%)
Dissolved Ortho P (365.2)	26	0.0125	0.939	0.0939	0.2154	mg/L	12/26 (46%)
Soluble Reactive P (4500PF)	53	0.0005	1.9468	0.2804	0.5826	mg/L	51/53 (96%)
Total Dissolved P (365.2)	26	0.0125	0.965	0.118	0.2464	mg/L	16/26 (62%)
Total Dissolved P (4500PF)	53	0.001	2.0462	0.2873	0.5929	mg/L	51/53 (96%)
Total Dissolved P (6010)	13	0.533	2.307	0.9978	0.5296	mg/L	13/13 (100%)
Total Dissolved P (6020)	35	0.011	1.99	0.3069	0.606	mg/L	35/35 (100%)
Total ortho P (365.2)	26	0.0125	0.849	0.1207	0.2183	mg/L	14/26 (54%)
Total P (365.2)	26	0.0125	1.081	0.1621	0.2669	mg/L	19/26 (73%)
Total P (4500PF)	53	0.0046	2.1018	0.337	0.6256	mg/L	53/53 (100%)
Total P (6010)	13	0.49	2.43	1.0662	0.5524	mg/L	13/13 (100%)
Total P (6020)	35	0.005	2.03	0.3253	0.6161	mg/L	34/35 (97%)
Total Sulfate (SO4)	48	1.89	67.5	13.8256	16.8239	mg/L	48/48 (100%)
DOC	12	0.5	2.93	1.8117	0.9129	mg/L	9/12 (75%)
TOC	48	0.5	14.7	2.2625	2.3668	mg/L	34/48 (71%)
Total Dissolved Solids	48	64	462	205.063	76.4915	mg/L	48/48 (100%)
Total Suspended Solids	48	1	74	6.8958	13.2717	mg/L	34/48 (71%)
Conductivity	37	0.17	0.554	0.2936	0.1002	mmhos/cm	37/37 (100%)
pH	37	6.4	8.21	7.4673	0.4975	s.u.	37/37 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 4: Summary of Small Tributary Samples – High Flow Conditions

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	177	16	316	98.5254	45.0946	mg/L	177/177 (100%)
Campylobacter species	87	0.1	1	0.8763	0.2552	MPN*/100ml	0/87 (0%)
E. coli	87	1	81000	3297.78	9844.8565	MPN*/100ml	84/87 (97%)
Enterococcus Group	120	0.5	1200000	21689.1	155434.77	MPN*/100ml	115/120 (96%)
Fecal Coliform	118	0.5	81000	3208.83	10076.47	MPN*/100ml	114/118 (97%)
Salmonella species	87	1	14	1.3448	1.5006	MPN*/100ml	13/87 (15%)
Staphylococcus aureus	120	0.5	220000	2511.09	20401.366	MPN*/100ml	35/120 (29%)
Total Coliform	120	0.5	170000	7907.60	21655.446	MPN*/100ml	119/120 (99%)
Chloride	177	0.5	66.851	12.2849	10.2274	mg/L	176/177 (99%)
17a-estradiol	52	0.5	14	2.6683	2.73	ng/L	0/52 (0%)
17b-estradiol	52	0.5	14	3.2119	2.8417	ng/L	5/52 (10%)
Estriol	52	0.5	746	21.9635	104.1133	ng/L	5/52 (10%)
Estrone	52	0.5	15	3.329	3.2772	ng/L	5/52 (10%)
Dissolved Aluminum	179	0.005	0.44	0.0527	0.0438	mg/L	32/179 (18%)
Dissolved Antimony	179	0.0005	0.005	0.0013	0.0017	mg/L	6/179 (3%)
Dissolved Arsenic	179	0.0005	0.006	0.0015	0.0017	mg/L	51/179 (28%)
Dissolved Barium	179	0.02	0.076	0.0428	0.0104	mg/L	179/179 (100%)
Dissolved Beryllium	179	0.0005	0.0005	0.0005	0	mg/L	0/179 (0%)
Dissolved Boron	8	0.0005	0.102	0.0308	0.0433	mg/L	6/8 (75%)
Dissolved Cadmium	179	0.0005	0.001	0.0006	0.0002	mg/L	0/179 (0%)
Dissolved Calcium	179	7.71	82.3	42.9434	16.8339	mg/L	179/179 (100%)
Dissolved Chromium	179	0.0005	0.005	0.0012	0.0011	mg/L	31/179 (17%)
Dissolved Cobalt	179	0.0005	0.011	0.0011	0.0015	mg/L	17/179 (9%)
Dissolved Copper	179	0.0005	0.01	0.0033	0.0018	mg/L	147/179 (82%)
Dissolved Iron	179	0.005	0.946	0.0674	0.098	mg/L	50/179 (28%)
Dissolved Lead	179	0.0005	0.008	0.001	0.0011	mg/L	1/179 (1%)
Dissolved Magnesium	179	0.744	5.62	2.5373	0.9884	mg/L	179/179 (100%)
Dissolved Manganese	179	0.0005	0.126	0.0044	0.0111	mg/L	121/179 (68%)
Dissolved Mercury	179	0.0001	0.0001	0.0001	0	mg/L	0/179 (0%)
Dissolved Molybdenum	176	0.0025	0.025	0.0061	0.0082	mg/L	1/176 (1%)
Dissolved Nickel	179	0.0005	0.005	0.002	0.0016	mg/L	106/179 (59%)
Dissolved Potassium	179	1.08	16.2	4.2345	2.7214	mg/L	179/179 (100%)
Dissolved Selenium	179	0.0005	0.005	0.0013	0.0017	mg/L	8/179 (4%)
Dissolved Silver	179	0.0005	0.0025	0.0008	0.0008	mg/L	0/179 (0%)
Dissolved Sodium	179	1.55	52.08	9.2825	9.0591	mg/L	179/179 (100%)
Dissolved Strontium	8	0.0005	0.0005	0.0005	0	mg/L	0/8 (0%)
Dissolved Thallium	179	0.0005	0.01	0.0021	0.0036	mg/L	0/179 (0%)
Dissolved Titanium	8	0.0005	0.0005	0.0005	0	mg/L	0/8 (0%)
Dissolved Vanadium	179	0.0005	0.005	0.0042	0.0016	mg/L	15/179 (8%)
Dissolved Zinc	179	0.0025	0.157	0.0148	0.0217	mg/L	137/179 (77%)
Total Aluminum	179	0.005	5.12	0.3136	0.6409	mg/L	121/179 (68%)
Total Antimony	179	0.0005	0.005	0.0013	0.0017	mg/L	7/179 (4%)
Total Arsenic	179	0.0005	0.005	0.0015	0.0017	mg/L	52/179 (29%)
Total Barium	179	0.022	0.082	0.0452	0.011	mg/L	179/179 (100%)
Total Beryllium	179	0.0005	0.0005	0.0005	0	mg/L	0/179 (0%)
Total Cadmium	179	0.0005	0.001	0.0006	0.0002	mg/L	0/179 (0%)
Total Calcium	179	7.72	137	43.0918	18.1683	mg/L	179/179 (100%)
Total Chromium	179	0.0005	0.008	0.0013	0.0012	mg/L	46/179 (26%)
Total Cobalt	179	0.0005	0.013	0.0013	0.0019	mg/L	4/179 (2%)
Total Copper	179	0.0005	0.061	0.0024	0.0046	mg/L	120/179 (67%)
Total Iron	179	0.005	4.838	0.3328	0.5467	mg/L	124/179 (69%)
Total Lead	179	0.0005	0.005	0.001	0.001	mg/L	12/179 (7%)
Total Magnesium	179	0.704	5.407	2.5016	0.9201	mg/L	179/179 (100%)
Total Manganese	179	0.0005	0.729	0.0236	0.0597	mg/L	158/179 (88%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 4: Summary of Small Tributary Samples – High Flow Conditions

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Mercury	179	0.0001	0.0001	0.0001	0	mg/L	0/179 (0%)
Total Molybdenum	166	0.0025	0.0025	0.0025	0	mg/L	0/166 (0%)
Total Nickel	179	0.0005	0.006	0.0017	0.001	mg/L	102/179 (57%)
Total Potassium	179	1.02	16.9	4.2827	2.7297	mg/L	179/179 (100%)
Total Selenium	179	0.0005	0.005	0.0013	0.0017	mg/L	6/179 (3%)
Total Silver	179	0.0005	0.0025	0.0008	0.0008	mg/L	0/179 (0%)
Total Sodium	179	1.33	51.41	9.1508	8.9871	mg/L	179/179 (100%)
Total Thallium	179	0.0005	0.01	0.0022	0.0036	mg/L	3/179 (2%)
Total Vanadium	179	0.0005	0.01	0.0043	0.0016	mg/L	19/179 (11%)
Total Zinc	179	0.0025	0.17	0.0154	0.0239	mg/L	129/179 (72%)
Ammonia Nitrogen	177	0.01	1.52	0.1087	0.1508	mg/L	77/177 (44%)
Nitrite + Nitrate (as N)	177	0.05	14.747	2.2773	2.1757	mg/L	173/177 (98%)
Total Kjeldahl Nitrogen	175	0.25	154	3.312	11.5331	mg/L	162/175 (93%)
Brevibacteria 16S rRNA	27	236.9971	175098.8	64590.7	76462.423	Copies/L	16/27 (59%)
Dissolved Ortho P (365.2)	74	0.0125	1.73	0.2299	0.3885	mg/L	42/74 (57%)
Soluble Reactive P (4500PF)	140	0.0005	2.23	0.2652	0.4615	mg/L	137/140 (98%)
Total Dissolved P (365.2)	68	0.0125	2.75	0.3008	0.5295	mg/L	49/68 (72%)
Total Dissolved P (4500PF)	140	0.005	2.4	0.2932	0.5022	mg/L	140/140 (100%)
Total Dissolved P (6010)	31	0.24	2.128	1.0329	0.5044	mg/L	31/31 (100%)
Total Dissolved P (6020)	148	0.005	2.15	0.2735	0.4457	mg/L	140/148 (95%)
Total ortho P (365.2)	73	0.0125	1.54	0.2118	0.3516	mg/L	37/73 (51%)
Total P (365.2)	74	0.0125	4.266	0.2842	0.5752	mg/L	50/74 (68%)
Total P (4500PF)	140	0.0062	2.44	0.3117	0.5067	mg/L	140/140 (100%)
Total P (6010)	31	0.29	2.14	1.0474	0.4956	mg/L	31/31 (100%)
Total P (6020)	148	0.005	2.26	0.2995	0.4545	mg/L	142/148 (96%)
Total Sulfate (SO4)	177	0.5	70.51	16.2586	13.6765	mg/L	176/177 (99%)
TOC	175	0.5	22.7	4.2535	2.8076	mg/L	171/175 (98%)
Total Dissolved Solids	177	0.05	3300	213.260	316.3209	mg/L	176/177 (99%)
Total Suspended Solids	177	1	236	11.2712	24.4546	mg/L	151/177 (85%)
Conductivity	109	0.092	0.55	0.2524	0.0844	mmhos/cm	109/109 (100%)
pH	169	5.1	8.28	7.265	0.6133	s.u.	169/169 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 5: Summary of Surface Water/Rivers Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	81	34	168	107.272	27.9231	mg/L	81/81 (100%)
Campylobacter species	15	0.335	1	0.6007	0.3002	MPN*/100ml	0/15 (0%)
E. coli	111	1	12000	463.82	1718.9989	MPN*/100ml	109/111 (98%)
Enterococcus Group	117	0.5	12000	606.013	1566.3641	MPN*/100ml	116/117 (99%)
Fecal Coliform	117	1	12000	824.333	2152.956	MPN*/100ml	116/117 (99%)
Salmonella species	111	1	56	1.7297	5.2361	MPN*/100ml	20/111 (18%)
Staphylococcus aureus	117	0.55	3900	53.1816	378.4555	MPN*/100ml	14/117 (12%)
Total Coliform	117	8	12000	2325.85	3617.4138	MPN*/100ml	117/117 (100%)
Chloride	108	1.19	86.2	15.6129	15.8287	mg/L	108/108 (100%)
Chlorophyll a	1	0.0036	0.0036	0.0036		mg/L	1/1 (100%)
Chlorophyll a, corrected	212	0.05	19	1.8665	2.3839	ug/L	210/212 (99%)
Chlorophyll a, uncorrected	212	0.05	21	2.6634	3.016	ug/L	211/212 (100%)
COD (Chemical Oxygen Demand)	13	6	12	8.9615	2.2681	mg/L	6/13 (46%)
17a-estradiol	83	0.5	2.503	0.536	0.2438	ng/L	2/83 (2%)
17b-estradiol	83	0.5	6.71	1.0928	1.5171	ng/L	15/83 (18%)
Estriol	83	0.5	0.5	0.5	0	ng/L	0/83 (0%)
Estrone	83	0.5	41.59	2.5887	7.7173	ng/L	9/83 (11%)
Dissolved Aluminum	91	0.005	0.05	0.0455	0.0135	mg/L	0/91 (0%)
Dissolved Antimony	91	0.0005	0.005	0.001	0.0014	mg/L	1/91 (1%)
Dissolved Arsenic	105	0.0005	0.006	0.0014	0.0015	mg/L	39/105 (37%)
Dissolved Barium	91	0.015	0.104	0.0512	0.0165	mg/L	91/91 (100%)
Dissolved Beryllium	91	0.0005	0.0005	0.0005	0	mg/L	0/91 (0%)
Dissolved Cadmium	91	0.0005	0.001	0.0005	0.0002	mg/L	0/91 (0%)
Dissolved Calcium	91	13.5	79.1	49.752	12.3192	mg/L	91/91 (100%)
Dissolved Chromium	91	0.0005	0.0025	0.001	0.0007	mg/L	39/91 (43%)
Dissolved Cobalt	91	0.0005	0.005	0.001	0.0014	mg/L	4/91 (4%)
Dissolved Copper	105	0.0005	0.01	0.0018	0.0018	mg/L	59/105 (56%)
Dissolved Iron	91	0.005	0.229	0.0483	0.0224	mg/L	6/91 (7%)
Dissolved Lead	91	0.0005	0.004	0.0008	0.0008	mg/L	4/91 (4%)
Dissolved Magnesium	91	1.3	6.89	2.3313	0.9162	mg/L	91/91 (100%)
Dissolved Manganese	91	0.0005	0.306	0.0156	0.0386	mg/L	83/91 (91%)
Dissolved Mercury	91	0.0001	0.0001	0.0001	0	mg/L	0/91 (0%)
Dissolved Molybdenum	82	0.0005	0.025	0.0028	0.0046	mg/L	11/82 (13%)
Dissolved Nickel	91	0.0005	0.008	0.0018	0.0019	mg/L	47/91 (52%)
Dissolved Potassium	91	1.11	26.3	4.5143	4.5193	mg/L	91/91 (100%)
Dissolved Selenium	91	0.0005	0.005	0.0011	0.0013	mg/L	22/91 (24%)
Dissolved Silver	91	0.0005	0.0025	0.0007	0.0006	mg/L	1/91 (1%)
Dissolved Sodium	91	2.33	102	13.2428	18.3595	mg/L	91/91 (100%)
Dissolved Thallium	91	0.0005	0.01	0.0014	0.0029	mg/L	0/91 (0%)
Dissolved Vanadium	91	0.0005	0.113	0.0069	0.0169	mg/L	5/91 (5%)
Dissolved Zinc	105	0.0025	0.044	0.0065	0.0072	mg/L	42/105 (40%)
Total Aluminum	91	0.005	0.453	0.0879	0.0803	mg/L	33/91 (36%)
Total Antimony	91	0.0005	0.01	0.0011	0.0017	mg/L	6/91 (7%)
Total Arsenic	105	0.0005	0.006	0.0015	0.0015	mg/L	48/105 (46%)
Total Barium	91	0.016	0.112	0.0532	0.0174	mg/L	91/91 (100%)
Total Beryllium	91	0.0005	0.001	0.0005	0.0001	mg/L	1/91 (1%)
Total Cadmium	91	0.0005	0.001	0.0005	0.0002	mg/L	0/91 (0%)
Total Calcium	91	13.8	79	50.0155	12.2445	mg/L	91/91 (100%)
Total Chromium	91	0.0005	0.003	0.0011	0.0007	mg/L	44/91 (48%)
Total Cobalt	91	0.0005	0.005	0.001	0.0014	mg/L	6/91 (7%)
Total Copper	105	0.0005	0.023	0.0013	0.0023	mg/L	33/105 (31%)
Total Iron	91	0.005	0.713	0.131	0.1365	mg/L	44/91 (48%)
Total Lead	91	0.0005	0.008	0.0011	0.0014	mg/L	13/91 (14%)
Total Magnesium	91	1.33	6.68	2.3584	0.9117	mg/L	91/91 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 5: Summary of Surface Water/Rivers Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Manganese	91	0.001	0.729	0.0382	0.0863	mg/L	87/91 (96%)
Total Mercury	91	0.0001	0.0001	0.0001	0	mg/L	0/91 (0%)
Total Molybdenum	81	0.0005	0.01	0.0021	0.0016	mg/L	12/81 (15%)
Total Nickel	91	0.0005	0.008	0.0017	0.0017	mg/L	52/91 (57%)
Total Potassium	91	1.02	26.4	4.5787	4.3758	mg/L	91/91 (100%)
Total Selenium	91	0.0005	0.005	0.0011	0.0013	mg/L	31/91 (34%)
Total Silver	91	0.0005	0.003	0.0007	0.0007	mg/L	2/91 (2%)
Total Sodium	91	2.3	98.9	13.5931	18.2596	mg/L	91/91 (100%)
Total Thallium	91	0.0005	0.01	0.0014	0.0029	mg/L	1/91 (1%)
Total Vanadium	91	0.0005	0.111	0.0188	0.0273	mg/L	34/91 (37%)
Total Zinc	105	0.0025	0.341	0.0101	0.0337	mg/L	39/105 (37%)
Ammonia Nitrogen	74	0.05	0.273	0.059	0.0376	mg/L	6/74 (8%)
Nitrite + Nitrate (as N)	347	0.05	14	1.5133	1.7799	mg/L	298/347 (86%)
Total Kjeldahl Nitrogen	345	0.25	10.1	1.6238	1.3784	mg/L	314/345 (91%)
Brevibacteria 16S rRNA	27	2855.611	329000	113985	186243.50	Copies/L	13/27 (48%)
Dissolved Ortho P (365.2)	33	0.0125	0.617	0.0395	0.1054	mg/L	9/33 (27%)
Soluble Reactive P (4500PF)	919	0.0005	14.7603	0.1085	0.5199	mg/L	911/919 (99%)
Total Dissolved P (365.2)	33	0.0125	0.663	0.0547	0.1128	mg/L	18/33 (55%)
Total Dissolved P (4500PF)	919	0.001	15.4509	0.1183	0.5447	mg/L	917/919 (100%)
Total Dissolved P (6010)	12	0.542	0.788	0.6691	0.0764	mg/L	12/12 (100%)
Total Dissolved P (6020)	93	0.005	1.43	0.1303	0.2246	mg/L	91/93 (98%)
Total ortho P (365.2)	32	0.0125	0.617	0.046	0.1063	mg/L	13/32 (41%)
Total P (365.2)	32	0.0125	0.733	0.061	0.1273	mg/L	17/32 (53%)
Total P (4500PF)	919	0.0044	15.7048	0.1466	0.6096	mg/L	919/919 (100%)
Total P (6010)	12	0.57	0.92	0.6867	0.0959	mg/L	12/12 (100%)
Total P (6020)	93	0.005	1.516	0.1463	0.2344	mg/L	92/93 (99%)
Total Sulfate (SO4)	81	1.52	101	17.7788	18.8386	mg/L	81/81 (100%)
DOC	67	0.5	9.07	2.3604	1.6414	mg/L	58/67 (87%)
TOC	461	0.5	18.6	2.2249	1.9563	mg/L	360/461 (78%)
Total Dissolved Solids	124	35	440	179.218	68.4266	mg/L	124/124 (100%)
Total Suspended Solids	124	1	53	5.0161	6.4126	mg/L	102/124 (82%)
Conductivity	4	0.19	0.276	0.2355	0.0403	mmhos/cm	4/4 (100%)
pH	69	6.3	8.3	7.2651	0.4005	s.u.	69/69 (100%)
Turbidity	20	0.5	5.18	1.3915	1.1553	NTU	12/20 (60%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 6: Summary of Surface Water/Rivers High Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	20	28	134	83.35	30.5154	mg/L	20/20 (100%)
Campylobacter species	14	0.5	1	0.9286	0.1816	MPN*/100ml	0/14 (0%)
E. coli	46	2	13000	658.087	2007.6099	MPN*/100ml	46/46 (100%)
Enterococcus Group	48	0.5	11000	843.823	1991.771	MPN*/100ml	47/48 (98%)
Fecal Coliform	48	5	13000	1064.38	2313.6484	MPN*/100ml	48/48 (100%)
Salmonella species	46	1	8	1.2609	1.0632	MPN*/100ml	6/46 (13%)
Staphylococcus aureus	47	0.55	150	4.9181	22.3808	MPN*/100ml	9/47 (19%)
Total Coliform	48	80	20000	3081.88	4779.9082	MPN*/100ml	48/48 (100%)
Chloride	28	0.5	32.3	10.4407	6.9343	mg/L	27/28 (96%)
Chlorophyll a, corrected	35	0.05	15	2.2471	3.2756	ug/L	34/35 (97%)
Chlorophyll a, uncorrected	35	0.1	18	3.0143	3.862	ug/L	35/35 (100%)
COD (Chemical Oxygen Demand)	6	5	14	8.6667	3.5449	mg/L	4/6 (67%)
17a-estradiol	19	0.5	3.25	1.2763	1.057	ng/L	0/19 (0%)
17b-estradiol	19	0.5	5.67	1.7516	1.473	ng/L	3/19 (16%)
Estriol	19	0.5	3.25	1.2763	1.057	ng/L	0/19 (0%)
Estrone	19	0.5	23.3	2.4763	5.1489	ng/L	1/19 (5%)
Dissolved Aluminum	23	0.005	0.277	0.0822	0.0783	mg/L	8/23 (35%)
Dissolved Antimony	23	0.0005	0.0005	0.0005	0	mg/L	0/23 (0%)
Dissolved Arsenic	24	0.0005	0.002	0.0007	0.0004	mg/L	7/24 (29%)
Dissolved Barium	23	0.026	0.086	0.046	0.0118	mg/L	23/23 (100%)
Dissolved Beryllium	23	0.0005	0.0005	0.0005	0	mg/L	0/23 (0%)
Dissolved Cadmium	23	0.0005	0.0005	0.0005	0	mg/L	0/23 (0%)
Dissolved Calcium	23	12	55.9	40.1223	11.5194	mg/L	23/23 (100%)
Dissolved Chromium	23	0.0005	0.003	0.0009	0.0007	mg/L	7/23 (30%)
Dissolved Cobalt	23	0.0005	0.001	0.0005	0.0001	mg/L	2/23 (9%)
Dissolved Copper	24	0.0005	0.007	0.0014	0.0014	mg/L	12/24 (50%)
Dissolved Iron	23	0.017	0.294	0.093	0.0828	mg/L	11/23 (48%)
Dissolved Lead	23	0.0005	0.001	0.0005	0.0001	mg/L	1/23 (4%)
Dissolved Magnesium	23	1.25	4.557	2.0647	0.7066	mg/L	23/23 (100%)
Dissolved Manganese	23	0.001	0.157	0.0145	0.0319	mg/L	23/23 (100%)
Dissolved Mercury	23	0.0001	0.0001	0.0001	0	mg/L	0/23 (0%)
Dissolved Molybdenum	22	0.0005	0.0025	0.0023	0.0005	mg/L	2/22 (9%)
Dissolved Nickel	23	0.0005	0.003	0.0012	0.0008	mg/L	13/23 (57%)
Dissolved Potassium	23	1.77	8.72	3.68	1.6819	mg/L	23/23 (100%)
Dissolved Selenium	23	0.0005	0.001	0.0005	0.0001	mg/L	2/23 (9%)
Dissolved Silver	23	0.0005	0.0005	0.0005	0	mg/L	0/23 (0%)
Dissolved Sodium	23	2.67	33.8	8.1882	7.4837	mg/L	23/23 (100%)
Dissolved Thallium	23	0.0005	0.0005	0.0005	0	mg/L	0/23 (0%)
Dissolved Vanadium	23	0.0005	0.009	0.0043	0.0019	mg/L	3/23 (13%)
Dissolved Zinc	24	0.0025	0.012	0.0059	0.0031	mg/L	16/24 (67%)
Total Aluminum	24	0.005	3.81	0.6905	1.1176	mg/L	15/24 (63%)
Total Antimony	24	0.0005	0.001	0.0005	0.0001	mg/L	1/24 (4%)
Total Arsenic	25	0.0005	0.002	0.0009	0.0005	mg/L	11/25 (44%)
Total Barium	24	0.028	0.091	0.0518	0.014	mg/L	24/24 (100%)
Total Beryllium	24	0.0005	0.0005	0.0005	0	mg/L	0/24 (0%)
Total Cadmium	24	0.0005	0.0005	0.0005	0	mg/L	0/24 (0%)
Total Calcium	24	11.8	61	38.9846	11.1614	mg/L	24/24 (100%)
Total Chromium	24	0.0005	0.007	0.0017	0.0021	mg/L	11/24 (46%)
Total Cobalt	24	0.0005	0.003	0.0008	0.0006	mg/L	5/24 (21%)
Total Copper	25	0.0005	0.005	0.0015	0.0014	mg/L	14/25 (56%)
Total Iron	24	0.015	6.39	0.9688	1.6566	mg/L	18/24 (75%)
Total Lead	24	0.0005	0.01	0.0019	0.0025	mg/L	7/24 (29%)
Total Magnesium	24	1.33	3.828	2.0855	0.6093	mg/L	24/24 (100%)
Total Manganese	24	0.002	0.357	0.0604	0.0951	mg/L	24/24 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

Appendix C: Water
Table 6: Summary of Surface Water/Rivers High Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Mercury	24	0.0001	0.0001	0.0001	0	mg/L	0/24 (0%)
Total Molybdenum	18	0.0005	0.0025	0.0023	0.0006	mg/L	2/18 (11%)
Total Nickel	24	0.0005	0.007	0.0019	0.0017	mg/L	15/24 (63%)
Total Potassium	24	1.87	9.46	3.7281	1.7124	mg/L	24/24 (100%)
Total Selenium	24	0.0005	0.001	0.0006	0.0002	mg/L	3/24 (13%)
Total Silver	24	0.0005	0.0005	0.0005	0	mg/L	0/24 (0%)
Total Sodium	24	2.44	35.2	7.9561	7.548	mg/L	24/24 (100%)
Total Thallium	24	0.0005	0.0005	0.0005	0	mg/L	0/24 (0%)
Total Vanadium	24	0.0005	0.088	0.0083	0.0172	mg/L	5/24 (21%)
Total Zinc	25	0.0025	0.028	0.0083	0.0073	mg/L	16/25 (64%)
Ammonia Nitrogen	17	0.05	0.222	0.0631	0.0427	mg/L	2/17 (12%)
Nitrite + Nitrate (as N)	56	0.19	7.28	1.6363	1.4432	mg/L	56/56 (100%)
Total Kjeldahl Nitrogen	59	0.25	15.7	2.7766	3.0908	mg/L	56/59 (95%)
Brevibacteria 16S rRNA	10					Copies/L	1/10 (10%)
Dissolved Ortho P (365.2)	5	0.0125	0.501	0.1212	0.2128	mg/L	3/5 (60%)
Soluble Reactive P (4500PF)	148	0.0027	1.6017	0.0734	0.1651	mg/L	148/148 (100%)
Total Dissolved P (365.2)	5	0.0125	1.014	0.2209	0.4437	mg/L	2/5 (40%)
Total Dissolved P (4500PF)	148	0.0047	1.8339	0.0855	0.1839	mg/L	148/148 (100%)
Total Dissolved P (6020)	24	0.015	1.118	0.1237	0.2201	mg/L	24/24 (100%)
Total ortho P (365.2)	5	0.0125	0.1565	0.0579	0.0597	mg/L	2/5 (40%)
Total P (365.2)	5	0.0125	1.014	0.2477	0.4293	mg/L	4/5 (80%)
Total P (4500PF)	148	0.0098	2.2298	0.1186	0.2216	mg/L	148/148 (100%)
Total P (6020)	25	0.034	1.09	0.1595	0.2085	mg/L	25/25 (100%)
Total Sulfate (SO4)	20	1.23	37.9	11.674	9.1856	mg/L	20/20 (100%)
TTHMFP as CHCl3	1	36.9	36.9	36.9		ug/L	1/1 (100%)
DOC	19	0.5	7.39	3.2542	2.071	mg/L	18/19 (95%)
TOC	66	0	7.38	2.308	1.6175	mg/L	57/66 (86%)
Total Dissolved Solids	32	78	256	150.875	38.7979	mg/L	32/32 (100%)
Total Suspended Solids	32	1	88	15.25	24.3986	mg/L	30/32 (94%)
Conductivity	6	0.12	0.269	0.1803	0.0514	mmhos/cm	6/6 (100%)
pH	12	6.5	7.3	6.8333	0.2188	s.u.	12/12 (100%)
Turbidity	10	0.5	46.7	7.115	14.1407	NTU	8/10 (80%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 7: Summary of USGS Sampling Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	69	69	142	106.362	15.047	mg/L	69/69 (100%)
Campylobacter species	13	1	1	1	0	MPN*/100ml	0/13 (0%)
E. coli	75	0.5	4000	99.46	480.3725	MPN*/100ml	67/75 (89%)
Enterococcus Group	80	1	4000	107.513	459.0388	MPN*/100ml	74/80 (93%)
Fecal Coliform	79	0.5	5400	160.709	667.2722	MPN*/100ml	75/79 (95%)
Fecal Streptococci	1	13	13	13		colonies per 100 milliliters	1/1 (100%)
Salmonella species	61	1	8	1.2131	0.933	MPN*/100ml	7/61 (11%)
Staphylococcus aureus	74	0.5	290	12.9791	47.3349	MPN*/100ml	13/74 (18%)
Total Coliform	86	8	16000	1088.98	2891.4381	MPN*/100ml	86/86 (100%)
Chloride	57	4.7	26	14.2279	6.5721	mg/L	57/57 (100%)
Chlorophyll a	7	0.8	6.5	2.8857	1.827	ug/L	7/7 (100%)
17a-estradiol	55	0.5	2.5	0.7045	0.5914	ng/L	0/55 (0%)
17b-estradiol	55	0.5	4.73	0.9978	1.0984	ng/L	5/55 (9%)
Estriol	55	0.5	2.5	0.7045	0.5914	ng/L	0/55 (0%)
Estrone	55	0.5	8.3	1.3361	1.7852	ng/L	9/55 (16%)
Dissolved Aluminum	60	0.0009	0.0539	0.0032	0.0069	mg/L	60/60 (100%)
Dissolved Antimony	60	0	0.0002	0.0001	0	mg/L	31/60 (52%)
Dissolved Arsenic	60	0.0002	0.001	0.0005	0.0002	mg/L	60/60 (100%)
Dissolved Barium	60	0.028	0.071	0.0487	0.0101	mg/L	60/60 (100%)
Dissolved Beryllium	60	0	0	0	0	mg/L	0/60 (0%)
Dissolved Cadmium	60	0	0	0	0	mg/L	19/60 (32%)
Dissolved Calcium	60	32.7	53.5	44.88	4.8897	mg/L	60/60 (100%)
Dissolved Chromium	60	0.0005	0.002	0.001	0.0003	mg/L	8/60 (13%)
Dissolved Cobalt	59	0	0.0006	0.0002	0.0001	mg/L	59/59 (100%)
Dissolved Copper	59	0.0002	0.0131	0.0014	0.0019	mg/L	52/59 (88%)
Dissolved Iron	60	0.003	0.016	0.0043	0.0025	mg/L	30/60 (50%)
Dissolved Lead	60	0	0.0003	0.0001	0.0001	mg/L	38/60 (63%)
Dissolved Magnesium	60	1.31	2.51	2.069	0.3086	mg/L	60/60 (100%)
Dissolved Manganese	60	0.0009	0.0277	0.0066	0.0061	mg/L	60/60 (100%)
Dissolved Mercury	49	0	0	0	0	mg/L	8/49 (16%)
Dissolved Molybdenum	60	0.0002	0.0021	0.0008	0.0004	mg/L	60/60 (100%)
Dissolved Nickel	59	0.0002	0.0042	0.0015	0.0011	mg/L	59/59 (100%)
Dissolved Potassium	60	1.66	6	3.9342	1.4062	mg/L	60/60 (100%)
Dissolved Selenium	60	0.0001	0.0004	0.0002	0.0001	mg/L	60/60 (100%)
Dissolved Silver	60	0	0.0001	0.0001	0	mg/L	0/60 (0%)
Dissolved Sodium	60	2.86	24.8	12.3305	6.6698	mg/L	60/60 (100%)
Dissolved Thallium	60	0	0	0	0	mg/L	3/60 (5%)
Dissolved Vanadium	60	0.0002	0.0019	0.0008	0.0004	mg/L	60/60 (100%)
Dissolved Zinc	60	0.0004	0.0086	0.0023	0.0016	mg/L	58/60 (97%)
Total Aluminum	60	0.001	0.261	0.0492	0.058	mg/L	60/60 (100%)
Total Antimony	60	0	0.0002	0.0001	0	mg/L	23/60 (38%)
Total Arsenic	57	0.0002	0.001	0.0006	0.0002	mg/L	48/57 (84%)
Total Barium	60	0.0268	0.0699	0.0485	0.0103	mg/L	60/60 (100%)
Total Beryllium	60	0	0	0	0	mg/L	1/60 (2%)
Total Cadmium	60	0	0	0	0	mg/L	26/60 (43%)
Total Calcium	60	32.9	56.3	44.5617	4.8685	mg/L	60/60 (100%)
Total Chromium	60	0.0004	0.001	0.0007	0.0003	mg/L	6/60 (10%)
Total Cobalt	57	0	0.0008	0.0002	0.0002	mg/L	57/57 (100%)
Total Copper	57	0.0003	0.0045	0.0009	0.0007	mg/L	38/57 (67%)
Total Iron	60	0.003	0.308	0.0664	0.0772	mg/L	59/60 (98%)
Total Lead	60	0	0.0006	0.0001	0.0001	mg/L	54/60 (90%)
Total Magnesium	60	1.2	2.43	1.9802	0.2919	mg/L	60/60 (100%)
Total Manganese	60	0.0015	0.061	0.0125	0.0138	mg/L	60/60 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 7: Summary of USGS Sampling Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Mercury	49	0	0	0	0	mg/L	10/49 (20%)
Total Molybdenum	60	0.0002	0.0019	0.0008	0.0004	mg/L	60/60 (100%)
Total Nickel	57	0.0001	0.0033	0.001	0.0006	mg/L	57/57 (100%)
Total Potassium	60	1.51	6.2	3.8337	1.3665	mg/L	60/60 (100%)
Total Selenium	57	0.0001	0.0008	0.0003	0.0002	mg/L	57/57 (100%)
Total Silver	60	0	0.0001	0	0	mg/L	0/60 (0%)
Total Sodium	60	2.6	24.3	12.0783	6.5657	mg/L	60/60 (100%)
Total Thallium	60	0	0.0001	0.0001	0	mg/L	3/60 (5%)
Total Vanadium	60	0.0005	0.002	0.001	0.0003	mg/L	24/60 (40%)
Total Zinc	57	0.001	0.003	0.0012	0.0005	mg/L	25/57 (44%)
Agency analyzing sample, code	36	80020	80020	80020	0	NA	36/36 (100%)
Air Temperature	98	-3.3	39.3	21.5867	10.281	C	98/98 (100%)
Altitude of land surface, feet	9	664.14	893.78	787.12	109.5435	feet	9/9 (100%)
ANC as CaCO3	1	91	91	91		mg/L as CaCO3	1/1 (100%)
Barometric pressure	102	729	755	741.471	4.9746	mmHg	102/102 (100%)
Discharge	95	6.3	2280	172.175	329.9262	cfs	95/95 (100%)
Drainage area, square miles	11	89.6	959	498.927	369.4605	sq miles	11/11 (100%)
Gage height	102	1.58	9.95	4.3475	1.5329	feet	102/102 (100%)
Loss on ignition	1	1	1	1		mg/L	1/1 (100%)
Pheophytin a	7	0.4	3200	1401.13	1505.429	ug/L	7/7 (100%)
Phytoplankton Biomass - Ash Free Dry Mass	4	1.5	1.7	1.6125	0.0854	mg/L	0/4 (0%)
Phytoplankton Biomass - Ash Free Dry Mass	3	1.6	1.9	1.7667	0.1528	ug/L	0/3 (0%)
Phytoplankton Biomass - Ash Weight	4	127	153	141.75	11.7011	mg/L	4/4 (100%)
Phytoplankton Biomass - Dry Weight	4	129	155	144	11.9164	mg/L	4/4 (100%)
Residue	22	103	201	152.682	31.3997	mg/L	22/22 (100%)
Residue	22	0.16	0.3	0.2291	0.0422	tons per acre-foot	22/22 (100%)
Residue	18	6.71	216	81.06	71.5268	tons per day	18/18 (100%)
Residue on evap.	46	112	234	177.533	33.4811	mg/L	46/46 (100%)
Sampler type, code	29	3044	3060	3045.31	2.8549	NA	29/29 (100%)
Sampling method, code	30	10	40	18.6667	13.5782	NA	30/30 (100%)
Suspended sediment <0.063 mm	37	48	100	75.7838	15.1385	%	37/37 (100%)
Suspended sediment <0.063 mm	10	56	87	71	9.0062	<.063mm	10/10 (100%)
Suspended sediment concentration	47	0	42	7.5532	8.2668	mg/L	47/47 (100%)
Total Residue	1	2	2	2		mg/L	1/1 (100%)
Turbidity - IR LEE Light	81	0	260	6.9605	29.5943	FNU	80/81 (99%)
Turbidity - White Light	101	1	12	2.1802	2.3092	NTRU	33/101 (33%)
Ammonia	96	0.005	2.53	0.0424	0.2585	mg/L as N	60/96 (63%)
Ammonia (as NH4)	1	0.42	0.42	0.42		mg/L as NH4	1/1 (100%)
Ammonia Nitrogen	96	0.05	3.2	0.2496	0.3989	mg/L as N	93/96 (97%)
Nitrate	21	2.95	58.2	16.9305	12.7108	mg/L	21/21 (100%)
Nitrate (as N)	21	0.67	13.1	3.8229	2.8636	mg/L as N	21/21 (100%)
Nitrite	21	0.007	0.133	0.0189	0.0267	mg/L	21/21 (100%)
Nitrite (as N)	96	0.001	0.188	0.0062	0.0193	mg/L as N	93/96 (97%)
Nitrite + Nitrate (as N)	95	0.184	13.1	2.1099	1.9242	mg/L as N	95/95 (100%)
Organic nitrogen	1	0.42	0.42	0.42		mg/L	1/1 (100%)
Total nitrogen	20	0.89	13	4.3295	2.8851	mg/L	20/20 (100%)
Dissolved Phosphorus	96	0.013	1.99	0.1537	0.3138	mg/L	96/96 (100%)
Orthophosphate	124	0.006	5.03	0.2864	0.732	mg/L	124/124 (100%)
Total Phosphorus	96	0.017	2.11	0.163	0.3201	mg/L	96/96 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

Appendix C: Water
Table 7: Summary of USGS Sampling Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Sulfate	57	5	27.4	14.8856	6.2662	mg/L	57/57 (100%)
TOC	64	0.7	4.8	1.6641	0.7745	mg/L	64/64 (100%)
Bicarbonate	72	84	172	128.736	17.7105	mg/L	72/72 (100%)
Biomass/chlorophyll ratio	3	462	1570	971.333	559.3758	number	3/3 (100%)
Carbonate	72	0	3	0.4861	0.5033	mg/L	32/72 (44%)
Dissolved oxygen (%)	29	81	145	107.586	14.5124	%	29/29 (100%)
DO	103	3.3	16.7	9.9961	2.5007	mg/L	103/103 (100%)
Hardness (as CaCO3)	22	89	140	117.136	14.3271	mg/L as CaCO3	22/22 (100%)
Hydrogen ion	30	0	0	0	0	mg/L	30/30 (100%)
Noncarbonate hardness (as CaCO3) - filtered	22	4	37	19.7273	8.4975	mg/L as CaCO3	22/22 (100%)
Noncarbonate hardness (as CaCO3) - unfiltered	1	11	11	11		mg/L as CaCO3	1/1 (100%)
pH	105	6.4	8.7	7.8429	0.3749	s.u.	105/105 (100%)
Sodium adsorption ratio	22	0.1	0.7	0.3909	0.2022	number	22/22 (100%)
Sodium fraction of cations	22	6	23	13.9545	5.9078	%	22/22 (100%)
Specific Conductance	13	31	395	295.769	107.9662	ms/cm at 25C	13/13 (100%)
Specific conductance	76	193	448	312.592	64.7022	uS/cm	76/76 (100%)
Specific conductance	74	201	590	311.622	74.0344	uS/cm 25C	74/74 (100%)
Suspended sediment discharge	6	0.13	13	3.3017	5.1491	tons per day	6/6 (100%)
Water Temperature	105	5.5	29.4	18.0552	7.2788	C	105/105 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 8: Summary of USGS Sampling High Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	94	9	126	87.3085	25.8324	mg/L	94/94 (100%)
Campylobacter species	18	1	1	1	0	MPN*/100ml	0/18 (0%)
E. coli	103	0.5	24000	2533.79	4185.7262	MPN*/100ml	102/103 (99%)
Enterococcus Group	103	0.5	170000	4484.9	17372.438	MPN*/100ml	102/103 (99%)
Fecal Coliform	88	0.5	14000	2506.52	3772.8115	MPN*/100ml	87/88 (99%)
Salmonella species	86	1	18	1.6628	2.5558	MPN*/100ml	14/86 (16%)
Staphylococcus aureus	91	0.55	2600	49.1681	292.5026	MPN*/100ml	9/91 (10%)
Total Coliform	108	18	540000	14332.5	55351.981	MPN*/100ml	108/108 (100%)
Chloride	80	2.46	29.7	12.8302	7.2159	mg/L	80/80 (100%)
Chlorophyll a	2	1.1	1.2	1.15	0.0707	ug/L	2/2 (100%)
17a-estradiol	92	0.5	12.5	1.5326	2.4962	ng/L	0/92 (0%)
17b-estradiol	92	0.5	12.5	1.6185	2.5284	ng/L	2/92 (2%)
Estriol	92	0.5	12.5	1.5326	2.4962	ng/L	0/92 (0%)
Estrone	92	0.5	16.1	1.909	3.1013	ng/L	5/92 (5%)
Dissolved Aluminum	83	0.001	0.0252	0.0039	0.0043	mg/L	83/83 (100%)
Dissolved Antimony	83	0	0.0002	0.0001	0	mg/L	54/83 (65%)
Dissolved Arsenic	83	0.0002	0.0011	0.0005	0.0002	mg/L	83/83 (100%)
Dissolved Barium	83	0.023	0.065	0.0454	0.0089	mg/L	83/83 (100%)
Dissolved Beryllium	83	0	0	0	0	mg/L	1/83 (1%)
Dissolved Cadmium	83	0	0.0001	0	0	mg/L	27/83 (33%)
Dissolved Calcium	83	19.1	50.1	40.5012	6.6137	mg/L	83/83 (100%)
Dissolved Chromium	83	0.0005	0.002	0.0009	0.0002	mg/L	7/83 (8%)
Dissolved Cobalt	82	0	0.0009	0.0002	0.0002	mg/L	82/82 (100%)
Dissolved Copper	82	0.0003	0.0174	0.0021	0.0028	mg/L	75/82 (91%)
Dissolved Iron	83	0.003	0.073	0.0121	0.0139	mg/L	70/83 (84%)
Dissolved Lead	83	0	0.0032	0.0002	0.0004	mg/L	53/83 (64%)
Dissolved Magnesium	83	1.02	2.52	1.99	0.2951	mg/L	83/83 (100%)
Dissolved Manganese	83	0.001	0.0245	0.0062	0.0058	mg/L	83/83 (100%)
Dissolved Mercury	47	0	0	0	0	mg/L	8/47 (17%)
Dissolved Molybdenum	83	0.0002	0.0019	0.0007	0.0004	mg/L	83/83 (100%)
Dissolved Nickel	81	0.0002	0.0048	0.0016	0.0012	mg/L	81/81 (100%)
Dissolved Potassium	83	1.89	7.13	4.0555	1.2709	mg/L	83/83 (100%)
Dissolved Selenium	83	0.0001	0.0005	0.0003	0.0001	mg/L	83/83 (100%)
Dissolved Silver	83	0	0.0001	0.0001	0	mg/L	0/83 (0%)
Dissolved Sodium	83	1.62	29.8	11.0342	7.0076	mg/L	83/83 (100%)
Dissolved Thallium	83	0	0	0	0	mg/L	1/83 (1%)
Dissolved Vanadium	83	0.0002	0.0016	0.0007	0.0003	mg/L	83/83 (100%)
Dissolved Zinc	83	0.0004	0.0851	0.0044	0.0098	mg/L	78/83 (94%)
Total Aluminum	83	0.012	8.7	0.4825	1.3834	mg/L	83/83 (100%)
Total Antimony	83	0	0.0002	0.0001	0	mg/L	43/83 (52%)
Total Arsenic	82	0.0003	0.0048	0.0008	0.0007	mg/L	76/82 (93%)
Total Barium	83	0.0271	0.21	0.0535	0.0269	mg/L	83/83 (100%)
Total Beryllium	83	0	0.0014	0.0001	0.0002	mg/L	27/83 (33%)
Total Cadmium	83	0	0.0007	0	0.0001	mg/L	64/83 (77%)
Total Calcium	83	28.1	50.7	40.7855	5.7602	mg/L	83/83 (100%)
Total Chromium	83	0.0004	0.015	0.0013	0.0025	mg/L	26/83 (31%)
Total Cobalt	82	0	0.0133	0.0008	0.002	mg/L	82/82 (100%)
Total Copper	82	0.0004	0.0149	0.0016	0.0024	mg/L	71/82 (87%)
Total Iron	83	0.019	13.7	0.6753	2.0973	mg/L	83/83 (100%)
Total Lead	82	0	0.0253	0.0013	0.004	mg/L	77/82 (94%)
Total Magnesium	83	1.36	2.52	1.9766	0.2449	mg/L	83/83 (100%)
Total Manganese	83	0.0022	1.7	0.0818	0.2695	mg/L	83/83 (100%)
Total Mercury	47	0	0.0001	0	0	mg/L	19/47 (40%)
Total Molybdenum	83	0.0002	0.0017	0.0007	0.0004	mg/L	83/83 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

Appendix C: Water
Table 8: Summary of USGS Sampling High Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Nickel	82	0.0001	0.0235	0.0022	0.0039	mg/L	82/82 (100%)
Total Potassium	83	1.82	6.7	4.0064	1.2368	mg/L	83/83 (100%)
Total Selenium	82	0.0001	0.0008	0.0003	0.0001	mg/L	82/82 (100%)
Total Silver	83	0	0.0003	0	0	mg/L	15/83 (18%)
Total Sodium	83	1.6	29.8	10.9458	7.0695	mg/L	83/83 (100%)
Total Thallium	83	0	0.0002	0.0001	0	mg/L	3/83 (4%)
Total Vanadium	83	0.0005	0.02	0.0021	0.0037	mg/L	56/83 (67%)
Total Zinc	82	0.001	0.067	0.0047	0.0101	mg/L	64/82 (78%)
Agency analyzing sample, code	39	80020	80020	80020	0	NA	39/39 (100%)
Air Temperature	86	-4.5	41.6	18.7547	10.2884	C	86/86 (100%)
Altitude of land surface, feet	21	664.14	893.78	772.867	97.0897	feet	21/21 (100%)
Barometric pressure	105	711	757	741.61	6.8198	mmHg	105/105 (100%)
Discharge	90	17	43100	2100.27	6256.9328	cfs	90/90 (100%)
Drainage area, square miles	24	89.6	959	421.075	337.3931	sq miles	24/24 (100%)
Gage height	93	1.96	23.48	5.9611	3.1259	feet	93/93 (100%)
Pheophytin a	2	0.8	1	0.9	0.1414	ug/L	2/2 (100%)
Phytoplankton Biomass - Ash Free Dry Mass	2	1.5	2.5	2	0.7071	ug/L	0/2 (0%)
Residue	24	99	184	140.958	23.5104	mg/L	24/24 (100%)
Residue	24	0.16	0.28	0.2258	0.0335	tons per acre-foot	24/24 (100%)
Residue	23	60.9	908	333.561	257.0443	tons per day	23/23 (100%)
Residue on evap.	69	90	246	163.493	31.7266	mg/L	69/69 (100%)
Sample purpose, code	1	10	10	10		feet	1/1 (100%)
Sample purpose, code	7	10	10	10	0	NA	7/7 (100%)
Sample splitter type, field, code	6	60	60	60	0	NA	6/6 (100%)
Sampler type, code	34	3045	3061	3049.85	7.241	NA	34/34 (100%)
Sampling method, code	34	10	70	21.1765	15.7181	NA	34/34 (100%)
Suspended sediment <0.063 mm	32	48	100	82.5312	16.0784	%	32/32 (100%)
Suspended sediment <0.063 mm	7	67	100	84.7143	11.1013	<.063mm	7/7 (100%)
Suspended sediment concentration	39	2	1600	130.769	352.7225	mg/L	39/39 (100%)
Turbidity - IR LEE Light	85	0.5	780	59.1929	138.9649	FNU	84/85 (99%)
Turbidity - White Light	96	1	900	43.3698	134.6682	NTRU	77/96 (80%)
Ammonia	93	0.005	0.072	0.0184	0.0153	mg/L as N	61/93 (66%)
Ammonia (as NH4)	3	0.01	0.06	0.0367	0.0252	mg/L as NH4	3/3 (100%)
Ammonia Nitrogen	93	0.07	4.3	0.4771	0.6503	mg/L as N	92/93 (99%)
Nitrate	18	3.7	18.2	8.0739	3.4217	mg/L	18/18 (100%)
Nitrate (as N)	18	0.83	4.12	1.8233	0.774	mg/L as N	18/18 (100%)
Nitrite	18	0.007	0.051	0.0186	0.0116	mg/L	18/18 (100%)
Nitrite (as N)	93	0.001	0.019	0.0057	0.0043	mg/L as N	90/93 (97%)
Nitrite + Nitrate (as N)	92	0.019	4.53	1.793	0.9813	mg/L as N	92/92 (100%)
Organic nitrogen	3	0.47	0.69	0.55	0.1217	mg/L	3/3 (100%)
Total nitrogen	25	1	4.7	2.288	0.9833	mg/L	25/25 (100%)
Dissolved Phosphorus	93	0.009	0.37	0.1082	0.0779	mg/L	93/93 (100%)
Orthophosphate	119	0.003	0.896	0.1357	0.1381	mg/L	115/119 (97%)
Total Phosphorus	93	0.013	1.06	0.1756	0.1704	mg/L	93/93 (100%)
Sulfate	80	5.4	30.6	14.4122	6.5991	mg/L	80/80 (100%)
TOC	82	0.7	42.1	4.6549	6.5677	mg/L	82/82 (100%)
Bicarbonate	100	34	153	107.78	29.0547	mg/L	100/100 (100%)
Biomass/chlorophyll ratio	2	2360	4110	3235	1237.4369	number	2/2 (100%)
Carbonate	100	0	3	0.46	0.4533	mg/L	42/100 (42%)
Dissolved oxygen (%)	34	63	110	90.5882	11.5342	%	34/34 (100%)
DO	106	5.3	16.4	9.05	1.8148	mg/L	106/106 (100%)
Hardness (as CaCO3)	24	83	130	110.417	13.6793	mg/L as CaCO3	24/24 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 8: Summary of USGS Sampling High Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Hydrogen ion	34	0	0.0001	0	0	mg/L	34/34 (100%)
Noncarbonate hardness (as CaCO3) - filtered	24	4	41	21.7917	11.0177	mg/L as CaCO3	24/24 (100%)
pH	104	6.2	8.8	7.6346	0.3746	s.u.	104/104 (100%)
Sodium adsorption ratio	24	0.1	0.6	0.3625	0.1637	number	24/24 (100%)
Sodium fraction of cations	24	6	21	13.8333	4.9226	%	24/24 (100%)
Specific Conductance	29	101	359	230.586	71.0676	ms/cm at 25C	29/29 (100%)
Specific conductance	67	128	423	299.597	81.2948	uS/cm	67/67 (100%)
Specific conductance	84	184	357	269.369	42.5293	uS/cm 25C	84/84 (100%)
Suspended sediment discharge	7	1.1	462	109.929	165.0522	tons per day	7/7 (100%)
Water Temperature	106	7.4	26.2	17.416	5.8457	C	106/106 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 9: Summary of Lake Tenkiller Surface Water Samples

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	64	38	112	76.3438	15.1188	mg/L	64/64 (100%)
Campylobacter species	18	0.035	1	0.6356	0.4706	MPN*/100ml	0/18 (0%)
E. coli	39	1	69	3.7436	11.4311	MPN*/100ml	9/39 (23%)
Enterococcus Group	46	0.5	110	5.0652	16.5552	MPN*/100ml	11/46 (24%)
Fecal Coliform	46	0.5	1100	44.6739	168.1642	MPN*/100ml	24/46 (52%)
Salmonella species	39	1	2	1.0256	0.1601	MPN*/100ml	1/39 (3%)
Staphylococcus aureus	46	0.5	40	1.9902	6.0427	MPN*/100ml	3/46 (7%)
Total Coliform	46	0.5	810	92.8804	165.8161	MPN*/100ml	39/46 (85%)
Chloride	64	6.22	18.3	10.6625	2.6239	mg/L	64/64 (100%)
Chlorophyll a	11	0.0047	0.0204	0.0127	0.0042	mg/L	11/11 (100%)
Chlorophyll a, corrected	315	0.4	133.3	11.4387	11.7257	ug/L	315/315 (100%)
Chlorophyll a, uncorrected	315	0.6	151	12.8943	13.8781	ug/L	315/315 (100%)
COD (Chemical Oxygen Demand)	108	2.5	32	10.2731	5.1923	mg/L	59/108 (55%)
17a-estradiol	47	0.5	2.5	0.7979	0.7197	ng/L	0/47 (0%)
17b-estradiol	47	0.5	7.46	1.5064	1.7305	ng/L	10/47 (21%)
Estriol	47	0.5	2.5	0.7979	0.7197	ng/L	0/47 (0%)
Estrone	47	0.5	8.99	1.2747	1.5815	ng/L	7/47 (15%)
Dissolved Aluminum	86	0.005	0.177	0.0489	0.0279	mg/L	11/86 (13%)
Dissolved Antimony	86	0.0005	0.005	0.002	0.0021	mg/L	2/86 (2%)
Dissolved Arsenic	151	0.0005	0.005	0.0021	0.002	mg/L	36/151 (24%)
Dissolved Barium	86	0.027	0.061	0.0395	0.0069	mg/L	86/86 (100%)
Dissolved Beryllium	86	0.0005	0.0005	0.0005	0	mg/L	0/86 (0%)
Dissolved Cadmium	86	0.0005	0.001	0.0007	0.0002	mg/L	0/86 (0%)
Dissolved Calcium	86	19.845	46.4	32.9658	6.4589	mg/L	86/86 (100%)
Dissolved Chromium	86	0.0005	0.0025	0.0013	0.0009	mg/L	11/86 (13%)
Dissolved Cobalt	86	0.0005	0.005	0.0019	0.0021	mg/L	2/86 (2%)
Dissolved Copper	151	0.0005	0.0025	0.0011	0.0009	mg/L	4/151 (3%)
Dissolved Iron	86	0.005	0.221	0.0526	0.0375	mg/L	7/86 (8%)
Dissolved Lead	86	0.0005	0.003	0.0014	0.0012	mg/L	6/86 (7%)
Dissolved Magnesium	86	1.65	2.36	1.8964	0.1656	mg/L	86/86 (100%)
Dissolved Manganese	86	0.0005	0.704	0.0419	0.1101	mg/L	36/86 (42%)
Dissolved Mercury	86	0.0001	0.0001	0.0001	0	mg/L	0/86 (0%)
Dissolved Molybdenum	68	0.0025	0.025	0.0058	0.008	mg/L	0/68 (0%)
Dissolved Nickel	86	0.0005	0.005	0.0021	0.002	mg/L	24/86 (28%)
Dissolved Potassium	86	2.39	4.62	3.1027	0.5542	mg/L	86/86 (100%)
Dissolved Selenium	86	0.0005	0.005	0.002	0.0021	mg/L	0/86 (0%)
Dissolved Silver	86	0.0005	0.0025	0.0012	0.0009	mg/L	0/86 (0%)
Dissolved Sodium	86	4.504	13.8	7.4511	2.1527	mg/L	86/86 (100%)
Dissolved Thallium	86	0.0005	0.01	0.0036	0.0045	mg/L	0/86 (0%)
Dissolved Vanadium	86	0.0005	0.056	0.0085	0.0131	mg/L	10/86 (12%)
Dissolved Zinc	151	0.0025	0.026	0.0055	0.0031	mg/L	60/151 (40%)
Total Aluminum	52	0.005	1.427	0.1239	0.2712	mg/L	13/52 (25%)
Total Antimony	52	0.0005	0.0125	0.0038	0.0028	mg/L	4/52 (8%)
Total Arsenic	117	0.0005	0.005	0.0027	0.002	mg/L	43/117 (37%)
Total Barium	52	0.029	0.078	0.0403	0.0102	mg/L	52/52 (100%)
Total Beryllium	52	0.0005	0.001	0.0005	0.0001	mg/L	0/52 (0%)
Total Cadmium	52	0.0005	0.001	0.0008	0.0002	mg/L	0/52 (0%)
Total Calcium	52	19.965	41.986	30.9128	6.328	mg/L	52/52 (100%)
Total Chromium	52	0.0005	0.005	0.0021	0.001	mg/L	11/52 (21%)
Total Cobalt	52	0.0005	0.005	0.0033	0.0021	mg/L	5/52 (10%)
Total Copper	117	0.0005	0.0025	0.0014	0.001	mg/L	9/117 (8%)
Total Iron	52	0.005	2.497	0.2019	0.4238	mg/L	20/52 (38%)
Total Lead	52	0.0005	0.003	0.0021	0.0012	mg/L	6/52 (12%)
Total Magnesium	52	1.6	2.438	1.8796	0.2438	mg/L	52/52 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Appendix C: Water
Table 9: Summary of Lake Tenkiller Surface Water Samples

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Manganese	52	0.0025	1.05	0.0952	0.1977	mg/L	33/52 (63%)
Total Mercury	52	0	0.0001	0.0001	0	mg/L	0/52 (0%)
Total Molybdenum	28	0.0025	0.005	0.0027	0.0007	mg/L	0/28 (0%)
Total Nickel	52	0.0005	0.005	0.002	0.001	mg/L	12/52 (23%)
Total Potassium	52	2.05	4.79	2.9553	0.5139	mg/L	52/52 (100%)
Total Selenium	52	0.0005	0.005	0.0033	0.002	mg/L	11/52 (21%)
Total Silver	52	0.0005	0.005	0.0019	0.0011	mg/L	2/52 (4%)
Total Sodium	52	4.299	13.551	6.7126	2.1393	mg/L	52/52 (100%)
Total Thallium	52	0.0005	0.01	0.006	0.0047	mg/L	1/52 (2%)
Total Vanadium	52	0.0005	0.014	0.0043	0.0026	mg/L	3/52 (6%)
Total Zinc	117	0.0025	0.02	0.0041	0.0023	mg/L	11/117 (9%)
Ammonia Nitrogen	71	0.05	0.379	0.066	0.0614	mg/L	6/71 (8%)
Nitrite + Nitrate (as N)	432	0.024	2.164	0.3428	0.4264	mg/L	230/432 (53%)
Total Kjeldahl Nitrogen	436	0.15	16	2.1847	1.7855	mg/L	399/436 (92%)
Brevibacteria 16S rRNA	3	0	0	0		Copies/L	1/3 (33%)
Dissolved Ortho P (365.2)	176	0.0125	0.077	0.0137	0.0069	mg/L	5/176 (3%)
Soluble Reactive P (4500PF)	444	0.0005	0.126	0.0082	0.0158	mg/L	307/444 (69%)
Total Dissolved P (365.2)	176	0.0125	0.194	0.0171	0.0208	mg/L	12/176 (7%)
Total Dissolved P (4500PF)	444	0.001	0.126	0.0117	0.0168	mg/L	435/444 (98%)
Total Dissolved P (6010)	46	0.259	0.653	0.489	0.0929	mg/L	46/46 (100%)
Total Dissolved P (6020)	105	0.005	0.203	0.0196	0.0308	mg/L	41/105 (39%)
Total ortho P (365.2)	175	0.0125	0.346	0.0219	0.0371	mg/L	20/175 (11%)
Total P (365.2)	175	0.0125	0.426	0.0321	0.0569	mg/L	31/175 (18%)
Total P (4500PF)	444	0.0038	0.5345	0.0378	0.0563	mg/L	444/444 (100%)
Total P (6010)	48	0.31	0.71	0.5096	0.097	mg/L	48/48 (100%)
Total P (6020)	67	0.005	0.264	0.0489	0.0585	mg/L	54/67 (81%)
Total Sulfate (SO4)	64	7.56	7055	231.654	1233.1188	mg/L	64/64 (100%)
DOC	92	0.5	3.92	2.1522	0.5292	mg/L	91/92 (99%)
TOC	293	1.2	5.49	2.1469	0.5234	mg/L	293/293 (100%)
Total Dissolved Solids	382	0.05	282	130.249	32.1448	mg/L	379/382 (99%)
Total Suspended Solids	382	1	168	6.9877	14.7052	mg/L	284/382 (74%)
Conductivity	20	0.173	0.266	0.2063	0.025	mmhos/cm	20/20 (100%)
pH	20	6	8	7.34	0.4661	s.u.	20/20 (100%)
Turbidity	192	0.5	66.9	3.8074	7.1313	NTU	138/192 (72%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

Appendix C: Water
Table 10: Summary of Reference Streams Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Alkalinity (as CaCO3)	7	44	404	145.286	128.3546	mg/L	7/7 (100%)
Campylobacter species	3	0.5	0.5	0.5	0	MPN*/100ml	0/3 (0%)
E. coli	7	2	30	16.1429	10.8694	MPN*/100ml	7/7 (100%)
Enterococcus Group	10	2	460	83.5	140.3529	MPN*/100ml	10/10 (100%)
Fecal Coliform	10	5	46	25.3	13.4251	MPN*/100ml	10/10 (100%)
Salmonella species	7	1	1	1	0	MPN*/100ml	0/7 (0%)
Staphylococcus aureus	10	0.55	40	6.52	12.3788	MPN*/100ml	3/10 (30%)
Total Coliform	10	0.5	900	262.35	347.3919	MPN*/100ml	9/10 (90%)
Chloride	9	2.08	12.44	6.06	3.2762	mg/L	9/9 (100%)
Chlorophyll a, corrected	6	0.2	1.2	0.5833	0.3371	ug/L	6/6 (100%)
Chlorophyll a, uncorrected	6	0.3	1.7	0.8333	0.4676	ug/L	6/6 (100%)
17a-estradiol	7	0.5	0.5	0.5	0	ng/L	0/7 (0%)
17b-estradiol	7	0.5	6.13	2.6114	2.6933	ng/L	3/7 (43%)
Estriol	7	0.5	0.5	0.5	0	ng/L	0/7 (0%)
Estrone	7	0.5	6.94	1.42	2.4341	ng/L	1/7 (14%)
Dissolved Aluminum	7	0.005	0.05	0.0307	0.0241	mg/L	0/7 (0%)
Dissolved Antimony	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Arsenic	7	0.0005	0.001	0.0006	0.0002	mg/L	2/7 (29%)
Dissolved Barium	7	0.017	0.05	0.0304	0.0108	mg/L	7/7 (100%)
Dissolved Beryllium	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Cadmium	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Calcium	7	25.3	89.524	40.4409	22.3132	mg/L	7/7 (100%)
Dissolved Chromium	7	0.0005	0.001	0.0006	0.0002	mg/L	1/7 (14%)
Dissolved Cobalt	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Copper	7	0.0005	0.002	0.0008	0.0006	mg/L	2/7 (29%)
Dissolved Iron	7	0.005	0.05	0.0307	0.0241	mg/L	0/7 (0%)
Dissolved Lead	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Magnesium	7	1.04	1.736	1.4541	0.2715	mg/L	7/7 (100%)
Dissolved Manganese	7	0.0005	0.005	0.0028	0.0017	mg/L	6/7 (86%)
Dissolved Mercury	7	0.0001	0.0001	0.0001	0	mg/L	0/7 (0%)
Dissolved Molybdenum	7	0.0005	0.0025	0.0019	0.001	mg/L	0/7 (0%)
Dissolved Nickel	7	0.0005	0.001	0.0006	0.0002	mg/L	1/7 (14%)
Dissolved Potassium	7	1.16	2.064	1.503	0.3025	mg/L	7/7 (100%)
Dissolved Selenium	7	0.0005	0.001	0.0006	0.0002	mg/L	1/7 (14%)
Dissolved Silver	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Sodium	7	2.12	8.29	4.1304	2.0643	mg/L	7/7 (100%)
Dissolved Thallium	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Dissolved Vanadium	7	0.0005	0.005	0.0024	0.002	mg/L	0/7 (0%)
Dissolved Zinc	7	0.0025	0.007	0.0035	0.0018	mg/L	2/7 (29%)
Total Aluminum	7	0.013	0.337	0.0767	0.116	mg/L	4/7 (57%)
Total Antimony	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Arsenic	7	0.0005	0.002	0.0009	0.0006	mg/L	3/7 (43%)
Total Barium	7	0.019	0.051	0.0316	0.0107	mg/L	7/7 (100%)
Total Beryllium	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Cadmium	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Calcium	7	24.5	84.226	39.6307	20.3489	mg/L	7/7 (100%)
Total Chromium	7	0.0005	0.001	0.0006	0.0002	mg/L	1/7 (14%)
Total Cobalt	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Copper	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Iron	7	0.014	0.255	0.0646	0.0857	mg/L	4/7 (57%)
Total Lead	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Magnesium	7	1.03	1.815	1.4674	0.2983	mg/L	7/7 (100%)
Total Manganese	7	0.001	0.019	0.0071	0.006	mg/L	7/7 (100%)
Total Mercury	7	0.0001	0.0001	0.0001	0	mg/L	0/7 (0%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

Appendix C: Water
Table 10: Summary of Reference Streams Base Flow

Parameter	n	Min	Max	Avg	Standard Deviation	Units	Percent Detected
Total Molybdenum	7	0.0005	0.0025	0.0019	0.001	mg/L	0/7 (0%)
Total Nickel	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Potassium	7	1.21	2.585	1.6077	0.4646	mg/L	7/7 (100%)
Total Selenium	7	0.0005	0.001	0.0006	0.0002	mg/L	1/7 (14%)
Total Silver	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Sodium	7	2.16	8.598	4.2424	2.1651	mg/L	7/7 (100%)
Total Thallium	7	0.0005	0.0005	0.0005	0	mg/L	0/7 (0%)
Total Vanadium	7	0.001	0.014	0.005	0.0052	mg/L	5/7 (71%)
Total Zinc	7	0.0025	0.0025	0.0025	0	mg/L	0/7 (0%)
Ammonia Nitrogen	4	0.05	0.05	0.05	0	mg/L	0/4 (0%)
Nitrite + Nitrate (as N)	17	0.05	0.789	0.1858	0.207	mg/L	8/17 (47%)
Total Kjeldahl Nitrogen	17	0.25	3.6	1.3774	1.0292	mg/L	15/17 (88%)
Dissolved Ortho P (365.2)	3	0.0125	0.0125	0.0125	0	mg/L	0/3 (0%)
Soluble Reactive P (4500PF)	33	0.0005	0.0371	0.0053	0.0082	mg/L	25/33 (76%)
Total Dissolved P (365.2)	3	0.0125	0.0125	0.0125	0	mg/L	0/3 (0%)
Total Dissolved P (4500PF)	33	0.001	0.0401	0.0072	0.0082	mg/L	31/33 (94%)
Total Dissolved P (6020)	7	0.005	0.022	0.012	0.0072	mg/L	4/7 (57%)
Total ortho P (365.2)	3	0.0125	0.031	0.0187	0.0107	mg/L	1/3 (33%)
Total P (365.2)	3	0.0125	0.049	0.0308	0.0183	mg/L	2/3 (67%)
Total P (4500PF)	33	0.0042	0.095	0.0138	0.0178	mg/L	33/33 (100%)
Total P (6020)	7	0.005	0.043	0.0221	0.0146	mg/L	6/7 (86%)
Total Sulfate (SO4)	7	4.03	7.18	5.5257	1.1089	mg/L	7/7 (100%)
DOC	4	1.13	2.18	1.4575	0.4924	mg/L	4/4 (100%)
TOC	21	0.5	23.1	2.259	4.852	mg/L	14/21 (67%)
Total Dissolved Solids	7	63	257	123	64.6813	mg/L	7/7 (100%)
Total Suspended Solids	7	1	6	2.7143	1.8898	mg/L	4/7 (57%)
pH	4	6.7	7.9	7.325	0.5679	s.u.	4/4 (100%)

NOTES:
(1) Non-detects treated as 1/2 the detection limit for min/max/avg/st. dev calculations

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Decreasing Metal Runoff from Poultry Litter with Aluminum Sulfate

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ABSTRACT

Aluminum sulfate [$Al_2(SO_4)_3 \cdot 14H_2O$] applications to poultry litter can greatly reduce P concentrations in runoff from fields fertilized with poultry litter, as well as decrease NH_3 volatilization. The objective of this study was to evaluate metal runoff from plots fertilized with varying rates of alum-treated and untreated (normal) poultry litter. Alum-treated (10% alum by weight) and untreated litter was broadcast applied to small plots in tall fescue (*Festuca arundinacea* Schreb.). Litter application rates were 0, 2.24, 4.49, 6.73, and 8.98 Mg ha^{-1} (0, 1, 2, 3, and 4 tons acre^{-1}). Rainfall simulators were used to produce two runoff events, immediately after litter application and 7 d later. Both concentrations and loads of water-soluble metals increased linearly with litter application rates, regardless of litter type. Alum treatment reduced concentrations of As, Cu, Fe, and Zn, relative to untreated litter, whereas it increased Ca and Mg. Copper concentrations in runoff water from untreated litter were extremely high (up to 1 mg Cu L^{-1}), indicating a potential water quality problem. Soluble Al, K, and Na concentrations were not significantly affected by the type of litter. Reductions in trace metal runoff due to alum appeared to be related to the concentration of soluble organic C (SOC), as well as the affinity of SOC for trace metals. Metal runoff from alum-treated litter is less likely to cause environmental problems than untreated litter, since threats to the aquatic environment by Ca and Mg are far less than those posed by As, Cu, and Zn.

POULTRY LITTER often contains fairly high concentrations of heavy metals (Sims and Wolf, 1994; Moore et al., 1995a). Tufft and Nockels (1991) indicated that As, Co, Cu, Fe, Mn, Se, and Zn are added to poultry diets to prevent diseases, improve weight gains and feed conversion, and increase egg production. Most of the metals added pass directly through the bird, which leads to elevated levels in the manure.

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Several researchers have shown that the metal concentrations in the diet of poultry are highly correlated to that in the manure (Morrison, 1969; Kunkle et al., 1981). Kunkle et al. (1981) found Cu concentrations in poultry litter were linearly related to that in feed; however, the values found in the manure were concentrated by up to a factor of 3.25 compared to the values in the feed. Stephenson et al. (1990) found that Cu levels in manure were quite variable, with a range of 25 to 1003 mg Cu kg^{-1} litter.

Sims and Wolf (1994) expressed concern that high concentrations of metals in poultry manure could lead to crop toxicities where long-term applications of manure have been made. Several workers have shown that soils receiving applications of poultry litter for many years have high concentrations of As, Cu, and Zn, particularly near the soil surface (van der Watt et al., 1994; Kingery et al., 1994). These studies indicate a potential for nonpoint source metal pollution from fields fertilized with poultry litter. Little data is available on metal concentrations in runoff water from fields fertilized with manure. Edwards et al. (1997) conducted a study on small plots to determine the effectiveness of vegetated filter strips in reducing metal runoff from land fertilized with broiler litter. We found Cu and Zn concentrations in the runoff water as high as 0.7 and 0.1 mg L^{-1}, indicating a potential problem.

Although it is uncertain if metal runoff is a major problem with the use of animal manures, high P concentrations have been documented in runoff water from pastures fertilized with low to moderate amounts of poultry manure, causing concerns over the utilization of this valuable resource in areas of the USA where poultry production is high (Edwards and Daniel, 1992a,b; Sims and Wolf, 1994). Phosphorus is normally the limiting element for eutrophication in freshwater bodies, such as rivers, lakes, and reservoirs (Schindler, 1977). The majority (80–90%) of the P in runoff water

Abbreviations: Al, aluminum; As, arsenic; Ca, calcium; Cu, copper; Fe, iron; K, potassium; Mg, magnesium; Na, sodium; Zn, zinc; SOC, soluble organic carbon; FA, fulvic acid.

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from fields fertilized with poultry litter is dissolved P, which is the form most readily available to algae (Edwards and Daniel, 1993; Sonzogni et al., 1982). Recent research has shown that alum additions to poultry litter can decrease P solubility in the litter (Moore and Miller, 1994). Shreve et al. (1995) found that P runoff from fescue plots fertilized with alum-treated litter was 87% lower than plots fertilized with untreated litter. The fescue plots receiving alum-treated litter also had significantly higher yields, due to increased N availability. Subsequent research has shown that alum applications to litter greatly reduce ammonia volatilization, improving the fertilizer value of the litter (Moore et al., 1995b, 1996).

Ammonia volatilization from poultry manure results in high levels of NH_3 gas in the atmosphere of poultry-rearing facilities, which is very detrimental to the health of the birds and farm workers. Carlile (1984) indicated that the critical level of NH_3 for poultry is 25 µL L^{-1}. Above this concentration, NH_3 can cause decreased growth rates, decreased egg production, reduced feed efficiency, damage to the respiratory tract, immunosuppression, and retinal damage (Carlile, 1984). Although many different litter amendments have been tested to reduce NH_3 volatilization from poultry litter, the most effective are alum and phosphoric acid (Moore et al., 1995b, 1996). Recent studies on commercial broiler farms by Moore et al. (1995c, 1997) showed that alum applications to poultry litter resulted in increased weight gains and improved feed conversion. These improvements in poultry performance make this one of the few cost-effective best management practices that both reduces pollution and increases agricultural productivity. However, before this management practice is put into widespread usage, many different questions concerning the environmental impacts must be addressed. One of the most important questions with regards to alum use is its effect on metal runoff from litter. Therefore, the objective of this study was to determine the effect of aluminum sulfate additions to poultry litter on metal concentrations and loads in runoff water from plots fertilized with varying rates of litter.

MATERIALS AND METHODS

This study was conducted using 52 small plots (1.52 × 3.05 m, with 5% slope) located at the Main Agricultural Experiment Station of the University of Arkansas on a Captina silt loam soil (fine-silty, siliceous, mesic Typic Fragiudult), which had been in continuous fescue for 2 yr. The plots have runoff collection troughs at the downslope end that enables the collection of runoff water. There were a total of 13 treatments: four rates of alum-treated poultry litter, four rates of untreated poultry litter, four rates of ammonium nitrate, and one unfertilized control. Litter application rates were 2.24, 4.49, 6.73, and 8.98 Mg ha^{-1} (1, 2, 3, and 4 tons $acre^{-1}$). These rates are all below the maximum rate of poultry litter recommended by the University of Arkansas Cooperative Extension Service (5 tons $acre^{-1}$), and represent the range of application rates commonly used by growers in northwest Arkansas. Ammonium nitrate application rates were 65, 130, 195, and 260 kg N ha^{-1}, and were included to evaluate fescue growth and N uptake and will not be included in the discussion. It should be noted that the metal concentrations from the ammonium nitrate treatments were all very similar to the unfertilized controls. There were four replications per treatment in a randomized block design.

Soil samples (0–5 cm) were taken from each plot (10 cores/plot) prior to the study and analyzed for Mehlich III P and water-soluble P. The treatments were then randomized, based on Mehlich III P values, so that the average soil test P level for each treatment was as close as possible (within 1 mg P kg^{-1}) to the overall average of 131 mg P kg^{-1}. Since the only P fertilizer applied to these plots was poultry litter, we assumed that soil test P would be a good indicator of past manure applications and, hence, an indicator of the amount of metals added to the soil via manure.

The poultry litter used for this study was obtained from six commercial broiler houses located in northwest Arkansas that had been part of a study on the effects of alum on ammonia volatilization and poultry production (Moore et al., 1995c, 1997). Alum had been applied to half of the houses at a rate of 1816 kg $house^{-1}$ after each growout, except after the first flock when it was applied at 1362 kg $house^{-1}$. The alum was applied and mixed into the litter using a litter "de-caker". Chemical characteristics of the untreated and alum-treated litter used in this study are given in Table 1.

The tall fescue was cut to a height of 10 cm with a bagger-mower 2 d prior to litter application. Afterwards the plots were watered manually until runoff was initiated. This was done to reduce the variability in soil moisture conditions between the plots. Rainfall simulators (Edwards et al., 1992) were used to provide 5 cm h^{-1} precipitation events immediately after litter application and 7 d later. Rainfall was simulated for a sufficient duration to allow 30 min of continuous runoff from each plot. Runoff samples were collected during each event at 2.5, 7.5, 12.5, 17.5, 22.5, and 27.5 min after continuous runoff was observed. Runoff samples were collected in 1-L plastic containers. Time to runoff was recorded for each plot and collection time and volume of runoff per unit time were recorded for each runoff sample. The overall average runoff from all the plots was 1.64 cm for the first runoff event and 1.48 cm for the second event.

The six water samples from each plot were composited into

Table 1. Chemical characteristics of poultry litter used for runoff study. Data are from Moore et al. (1997).

Parameter	Alum-treated litter		Untreated litter	
	Average	SD	Average	SD
pH	7.59	0.77	8.04	0.18
EC, µS cm^{-1}	10 833	471	6 611	311
Total metals		g/kg		
N	38.5	1.1	34.5	2.7
S	33.9	9.8	6.8	0.4
Ca	29.4	3.6	34.1	4.2
K	27.4	2.7	26.4	1.6
P	18.9	1.8	22.4	1.7
Al	18.7	6.0	1.18	0.2
Na	7.54	0.6	7.84	0.6
Mg	5.79	0.7	6.57	0.4
		mg/kg		
Fe	1 717	310	1 095	155
Mn	893	216	956	134
Cu	679	93	748	102
Zn	598	51	718	69
B	46	4	51	4
Ti	31	11	44	19
As	20	8	43	4
Ni	21	5	15	2
Pb	8	2	11	2
Co	6	2	6	1
Mo	5	0.5	6	0.5
Cd	3	0.4	3	0.2

one sample, based on runoff volumes on a flow-weighted basis. A portion of each runoff water sample was filtered through a 0.45-μm membrane, acidified to pH 2 with concentrated HCl, and frozen for soluble metal analysis. Metal concentrations (Al, As, B, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mo, Mn, Na, Pb, Ni, Se, Ti, and Zn) were determined using a Spectro Model D ICP (Spectro Analytical Instruments, Fitchburg, MA).[1] The concentrations of Cd, Co, Cr, Mo, Pb, Se, and Ti were below detection limits and will not be reported. Soluble metal loads were calculated from soluble metal concentrations and total runoff volumes. Soluble organic C was determined on filtered, unacidified samples using a Dohrmann DC-190 High Temperature Total Organic Carbon Analyzer (Rosemount Analytical, Santa Clara, CA). Unfiltered samples were used for pH, electrical conductivity, alkalinity, and total metal determination. Total metals were analyzed with a Spectro Model D ICP after digestion with nitric acid according to APHA Method 3030E (American Public Health Association, 1992).

RESULTS AND DISCUSSION

Litter Characteristics

Chemical characteristics of the alum-treated litter were similar to untreated litter, except for total Al and total S, which were both much higher in the alum-treated litter (Table 1). The alum-treated litter also had a slightly lower pH than untreated litter (7.59 vs. 8.04) and a higher electrical conductivity (10 833 μS cm^{-1} vs. 6611 μS cm^{-1}).

Trace Metal Runoff

Copper Runoff

Soluble Cu concentrations in the runoff water of the unfertilized control plots averaged 0.010 mg Cu L^{-1} for the first runoff event and 0.014 mg Cu L^{-1} for the second event 7 d later (Fig. 1). These values are near the average (0.015 mg Cu L^{-1}) of that for natural waters in the USA (Manahan, 1991). The amount of soluble Cu in the runoff water increased linearly with litter application rate, regardless of litter type, but was significantly higher from normal litter than alum-treated litter (Fig. 1, Tables 2 and 3). At the highest litter application rate, the average soluble Cu concentration in the runoff water from untreated litter was 93 times higher than the control (0.93 mg Cu L^{-1}), while the average Cu level for the same rate of alum-treated litter was 52 times higher than the control (0.52 mg Cu L^{-1}). One week later, the average Cu concentration had decreased to 0.13 and 0.25 mg Cu L^{-1}, for the high rates of alum-treated and untreated litter. These values are similar to those of B.M. Hall (1993. Broiler litter effects on crop production, soil properties, and water quality. Masters thesis, Auburn Univ.) who found that average dissolved Cu concentrations in runoff from pastures fertilized with broiler litter at application rates of 9 and 18 Mg ha^{-1} were 0.028 and 0.032 mg L^{-1}, over a 2-yr period (on a 4% slope). The highest soluble Cu concentrations

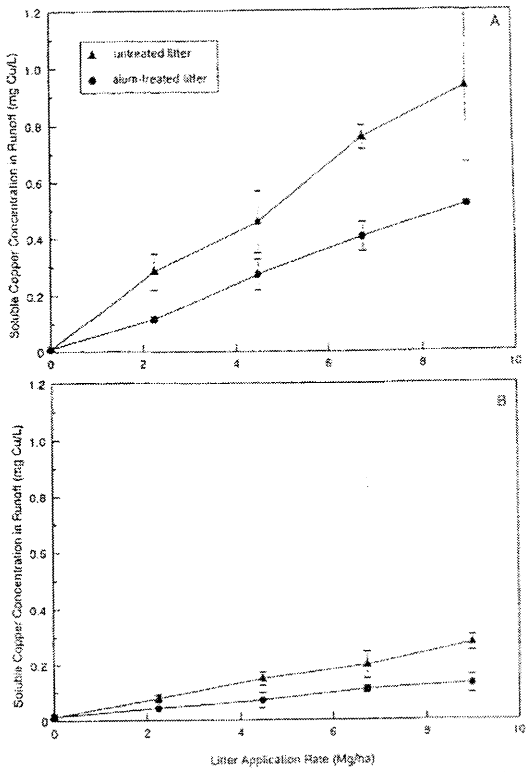

Fig. 1. Soluble Cu concentrations in runoff water from fescue plots fertilized with untreated and alum-treated poultry litter at (*A*) the day of application, (*B*) 7 d after application.

observed by B.M. Hall (1993. Broiler litter effects on crop production, soil properties, and water quality. Masters thesis, Auburn Univ.) were 0.35 and 0.32 mg L^{-1} for 9 and 18 Mg ha^{-1}.

The U.S. Public Health Service (1962) limit for Cu in drinking water is 1.0 mg Cu L^{-1}, which was exceeded by some of the samples in this study. Although it is unlikely that Cu would cause human health problems at this level, it is extremely toxic to algae at moderate levels and thus may pose a threat to the aquatic environment (Manahan, 1991). The highest value of Cu observed in an assessment of the waters of the USA was 0.280 mg Cu L^{-1}, which was exceeded in this study (Manahan, 1991).

Soluble Cu concentrations in the runoff were highly correlated with soluble organic C (SOC) levels (Fig. 2), which supports the findings of del Castilho et al. (1993), who showed that Cu concentrations in soil solutions were more affected by SOC than any other soil parameters. The data in Fig. 2 also indicate that the SOC from the alum-treated litter had less of an affinity for Cu than the SOC from untreated litter. The slope of the Cu-SOC relationship for the alum-treated litter was 0.0017, compared to 0.0028 for untreated litter. These data confirm the findings of Moore et al. (1995b), who showed

[1] Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply its approval to the exclusion of other products that may be suitable.

Table 2. Simple linear regression equations for soluble metal concentrations during the first runoff event as a function of litter application rate for the two types of poultry litter, with probabilities of significant differences in slopes between the two equations.

Treatment	Element	Equation	Pr > F
Untreated Alum-treated	Al	$y = 0.012x + 0.134$ $y = 0.013x + 0.111$	0.9140
Untreated Alum-treated	As	$y = 0.022x + 0.030$ $y = 0.009x + 0.020$	0.0047
Untreated Alum-treated	Ca	$y = -0.30x + 25.1$ $y = 4.74x + 21.9$	0.0001
Untreated Alum-treated	Cu	$y = 0.100x + 0.047$ $y = 0.059x - 0.006$	0.0157
Untreated Alum-treated	Fe	$y = 0.058x + 0.050$ $y = 0.021x + 0.050$	0.0043
Untreated Alum-treated	K	$y = 22.7x + 15.5$ $y = 31.3x - 1.64$	0.0247
Untreated Alum-treated	Mg	$y = 0.19x + 4.61$ $y = 1.37x + 2.91$	0.0001
Untreated Alum-treated	Mn	$y = 0.014x + 0.09$ $y = 0.038x - 0.02$	0.0005
Untreated Alum-treated	Na	$y = 6.92x + 6.08$ $y = 8.88x + 0.71$	0.0812
Untreated Alum-treated	Zn	$y = 0.043x + 0.052$ $y = 0.018x + 0.087$	0.0001

soluble Cu levels were lower in alum-treated litter and were highly correlated to SOC.

It is possible that the dissolved humic materials of the alum-treated litter (pH 7.59) had less Cu adsorbed to it than that of untreated litter (pH 8.04) because of competitive proton sorption or pH-dependent metal complexation. Hesterberg et al. (1993) indicated that equilibrium constant for fulvic acid (FA) complexation of Cu had a linear dependence on pH. Another possible mechanism to explain this behavior would be sorption of Cu onto $Al(OH)_3$ which forms in the litter as a result of alum application.

Water-soluble Cu was highly correlated ($R = 0.999$)

Table 3. Simple linear regression equations for soluble metal concentrations during the second runoff event as a function of litter application rate for the two types of poultry litter, with probabilities of significant differences in slopes between the two equations.

Treatment	Element	Equation	Pr > F
Untreated Alum-treated	Al	$y = 0.005x + 0.15$ $y = 0.009x + 0.11$	0.6287
Untreated Alum-treated	As	$y = 0.004x + 0.05$ $y = 0.004x + 0.02$	0.8695
Untreated Alum-treated	Ca	$y = -0.628x + 21.4$ $y = -0.048x + 21.9$	0.2046
Untreated Alum-treated	Cu	$y = 0.029x + 0.01$ $y = 0.013x + 0.02$	0.0005
Untreated Alum-treated	Fe	$y = 0.020x + 0.01$ $y = 0.006x + 0.02$	0.0001
Untreated Alum-treated	K	$y = 5.73x + 6.6$ $y = 3.70x + 8.3$	0.0705
Untreated Alum-treated	Mg	$y = 0.22x + 4.1$ $y = 0.39x + 3.6$	0.2218
Untreated Alum-treated	Mn	$y = 0.004x + 0.04$ $y = 0.008x + 0.03$	0.2607
Untreated Alum-treated	Na	$y = 1.94x + 4.8$ $y = 1.21x + 5.0$	0.0556
Untreated Alum-treated	Zn	$y = 0.0002x + 0.1$ $y = 0.004x - 0.1$	0.6347

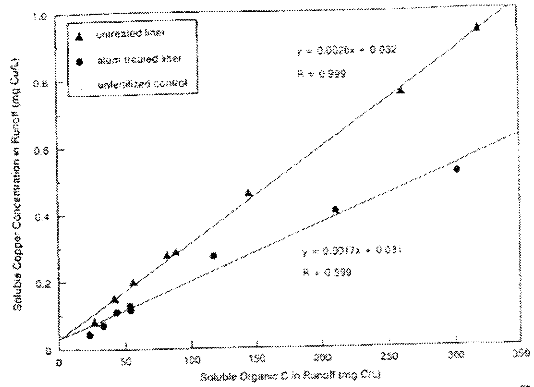

Fig. 2. The relationship between soluble Cu concentrations in runoff and soluble organic C levels.

with total Cu in the runoff water (Fig. 3). Approximately 95% of the total Cu was in the water-soluble form, indicating that there was very little particulate Cu runoff. This was the case for all the metals investigated in this study, with the exception of Al and Fe.

Soluble Cu loads from alum-treated and untreated litter followed the same patterns as Cu concentrations, as shown in Table 4. Copper loads from the controls were approximately 2 g Cu ha^{-1} for both runoff events. At the highest rate of litter application, Cu loads were 151 g Cu ha^{-1} for untreated litter and 83 g Cu ha^{-1} for the alum-treated litter for the first runoff event. It should be kept in mind that the results from this study represent a worse-case scenario, since the litter was applied immediately prior to a heavy rainfall.

Zinc Runoff

Soluble Zn concentrations in the runoff water from control plots were 0.047 and 0.043 mg Zn L^{-1} for the first and second runoff event (Fig. 4a,b). These values are slightly below the average (0.064 mg Zn L^{-1}) of that for natural waters in the USA (Manahan, 1991). As with Cu, the Zn concentrations of the runoff water increased with the litter application rate for both types of litter

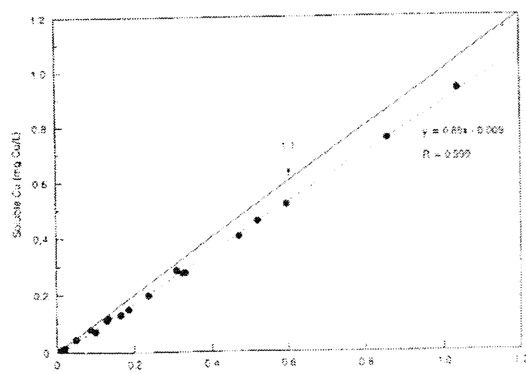

Fig. 3. The relationship between soluble and total Cu concentrations in runoff water.

Table 4. Soluble metal loads in runoff from alum-treated and untreated poultry litter.

Treatment	Al	As	Ca	Cu	Fe	K	Mg	Na	Zn
	g ha^{-1}								
First runoff event									
Control	22.0	4.8	3 858	1.7	3.7	1 623	693	782	8.0
2.24 Mg alum-treated litter/ha	21.7	6.1	5 545	19.9	15.1	10 909	1 143	3 906	19.1
4.49 Mg alum-treated litter/ha	25.5	11.4	7 460	46.7	26.7	24 923	1 455	7 164	32.3
6.73 Mg alum-treated litter/ha	31.8	13.2	9 016	68.8	33.9	35 323	1 864	10 163	36.7
8.98 Mg alum-treated litter/ha	35.7	15.5	10 464	83.0	37.8	44 127	2 578	12 823	38.3
2.24 Mg untreated litter/ha	28.5	14.2	4 091	48.4	33.7	12 559	849	4 012	27.1
4.49 Mg untreated litter/ha	31.1	20.0	3 970	78.1	48.0	18 014	930	5 762	37.8
6.73 Mg untreated litter/ha	36.5	33.3	4 338	129	75.0	29 147	1 037	9 130	62.1
8.98 Mg untreated litter/ha	40.4	35.7	3 418	151	94.2	35 511	989	10 997	70.2
$LSD_{0.05}$	10.9	7.4	1 843	27	19.8	5 578	392	1 734	9.9
Second runoff event									
Control	23.1	5.3	3 348	2.3	2.3	1 327	531	706	7.3
2.24 Mg alum-treated litter/ha	26.0	6.8	3 824	7.5	6.4	2 763	823	1 311	8.3
4.49 Mg alum-treated litter/ha	20.4	5.3	3 233	12.1	7.1	3 917	834	1 636	7.7
6.73 Mg alum-treated litter/ha	24.3	7.9	3 762	18.7	10.7	6 498	1 074	2 493	9.5
8.98 Mg alum-treated litter/ha	32.6	10.3	3 359	20.5	12.1	6 220	1 157	2 402	12.6
2.24 Mg untreated litter/ha	28.2	10.2	3 407	13.2	9.0	3 379	806	1 572	12.1
4.49 Mg untreated litter/ha	30.2	10.6	3 102	25.2	17.4	5 532	863	2 299	25.8
6.73 Mg untreated litter/ha	26.1	11.7	2 964	33.6	20.6	7 497	887	2 989	13.8
8.98 Mg untreated litter/ha	33.5	14.3	2 505	44.1	31.1	9 406	1 012	3 577	15.4
$LSD_{0.05}$	10.3	3.7	771	6.3	4.4	1 698	205	579	12.5

on the first runoff event (Table 2). Zinc concentrations were an average of 56% higher in runoff water from untreated litter compared to alum-treated litter, for the first runoff event (0.295 vs. 0.189 mg Zn L^{-1}). At the highest litter application rate, Zn concentrations were 0.44 and 0.24 mg Zn L^{-1}, for untreated and alum-treated litter. Similar results were observed by B.M. Hall (1993, Broiler litter effects on crop production, soil properties, and water quality. Masters thesis, Auburn Univ.) who found average dissolved Zn concentrations of 0.25 and 0.27 mg L^{-1} in runoff from 9 and 18 Mg broiler litter ha^{-1}.

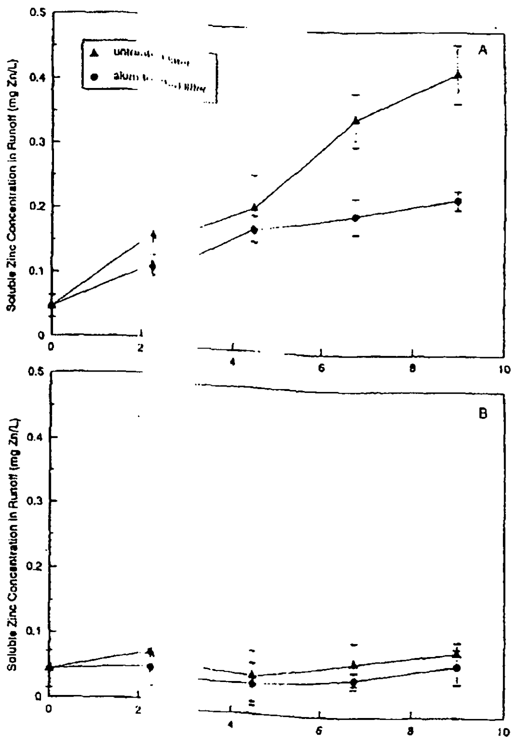

Fig. 4. Soluble Zn concentrations in runoff water from fescue plots fertilized with untreated and alum-treated poultry litter at (A) the day of application (B) 7 d after application.

Soluble Zn concentrations were much lower in runoff from both types of litter 7 d after litter application, with the highest litter rate resulting in Zn concentrations of 0.077 and 0.097 mg Zn L^{-1} (Fig. 4b, Table 3). It is unclear why Zn concentrations in runoff from plots receiving litter decreased to levels approaching background (0.04 mg Zn L^{-1}), while Cu runoff concentrations remained over an order of magnitude higher than the Cu concentrations observed in runoff from control plots. Zinc concentrations were highly correlated to SOC levels, as was Cu (data not shown).

The U.S. Public Health Service (1962) limit on Zn in drinking water is 5.0 mg Zn L^{-1}, which indicates that it is relatively harmless to animal life. Manahan (1991) indicated that the average Zn concentration in natural waters of the USA with detectable Zn was 0.064 mg Zn L^{-1}. This is very near the concentrations in runoff water 7 d after litter application, which indicates that these levels probably do not pose a problem.

As shown in Table 4, soluble Zn loads from alum-treated and untreated litter followed the same patterns as Zn concentrations. Zinc loads from the control plots were 8.0 and 7.3 g ha^{-1}, for the first and second runoff events. At the highest litter application rate, Zn loads were 38.3 and 70.2 g ha^{-1}, for alum-treated and untreated litter.

Arsenic Runoff

Soluble As concentrations in the runoff water from the unfertilized control plots were 0.028 and 0.031 mg

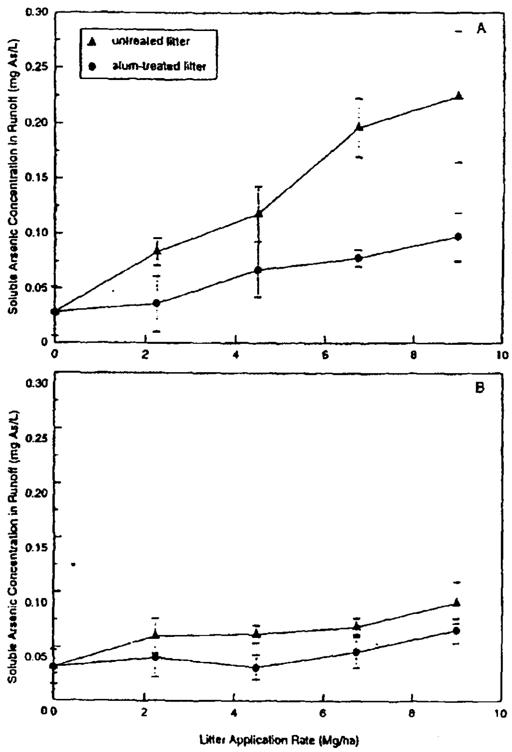

Fig. 5. Soluble As concentrations in runoff water from fescue plots fertilized with untreated and alum-treated poultry litter at (*A*) the day of application, (*B*) 7 d after application.

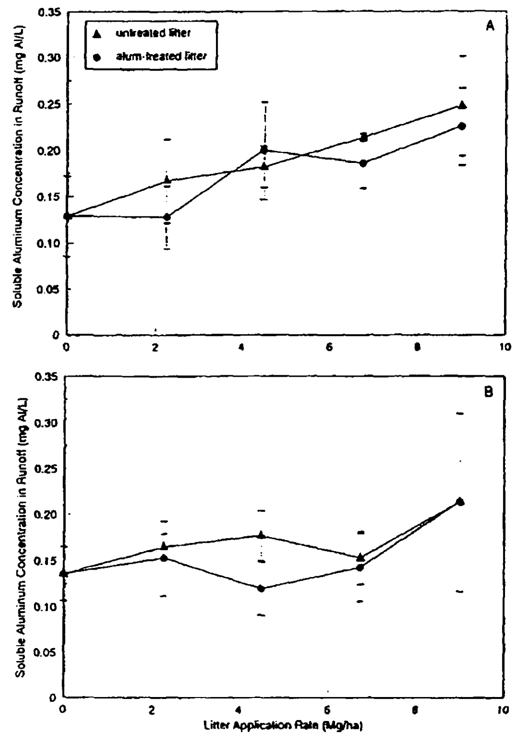

Fig. 6. Soluble Al concentrations in runoff water from fescue plots fertilized with untreated and alum-treated poultry litter at (*A*) the day of application, (*B*) 7 d after application.

As L^{-1} for the first and second runoff events. (Fig. 5a,b). Arsenic levels increased with increases in litter rates for the first runoff event, with significantly higher concentrations noted from the plots fertilized with normal litter (Fig. 5a, Table 2). The highest litter application rate resulting in mean As values of 0.097 and 0.224 mg As L^{-1} for the alum-treated and untreated poultry litter. On average, the As concentration in the runoff water of the plots fertilized with untreated poultry litter was 123% higher than the plots fertilized with alum-treated litter during the first runoff event (0.155 vs. 0.069 mg Al L^{-1}). Arsenic concentrations were highly correlated to SOC, as was Cu and Zn (data not shown).

Soluble As concentrations were much lower during the second runoff event than during the first (Fig. 5b). There were no significant effects due to the type of litter on As for the second runoff event (Table 3). The mean concentrations for the highest rates of litter were 0.091 and 0.066 mg As L^{-1} for untreated and alum-treated litter during the second runoff event.

The U.S. Public Health Service (1962) limit on As in drinking water is 0.05 mg As L^{-1}, which indicates that it is relatively toxic to animals. Manahan (1991) indicated that As may be carcinogenic, therefore, the levels of As observed in this study could potentially cause water quality problems.

Soluble As loads from alum-treated and untreated litter followed the same patterns as As concentrations, as shown in Table 4. Arsenic loads from the controls were approximately 5 g As ha^{-1} for both runoff events. At the highest rate of litter application, As loads were 35 g As ha^{-1} for untreated litter and 16 g As ha^{-1} for the alum-treated litter for the first runoff event and 10 and 14 g As ha^{-1} for the second runoff event.

Iron Runoff

Soluble Fe increased linearly with litter application rate, for both the alum-treated and untreated litter; however, the concentrations were significantly higher in runoff from untreated litter (Tables 2 and 3). Iron was one of the few elements where the soluble concentrations did not comprise the dominant fraction of the total. Soluble and total Fe concentrations in runoff from untreated litter were higher than that from alum-treated litter during both the first and second runoff events.

Aluminum Runoff

Soluble Al concentrations in the runoff from control plots were 0.129 and 0.136 mg Al L^{-1} for the first and second runoff event, respectively (Fig. 6a,b). The effects of litter application rate and litter type were not as

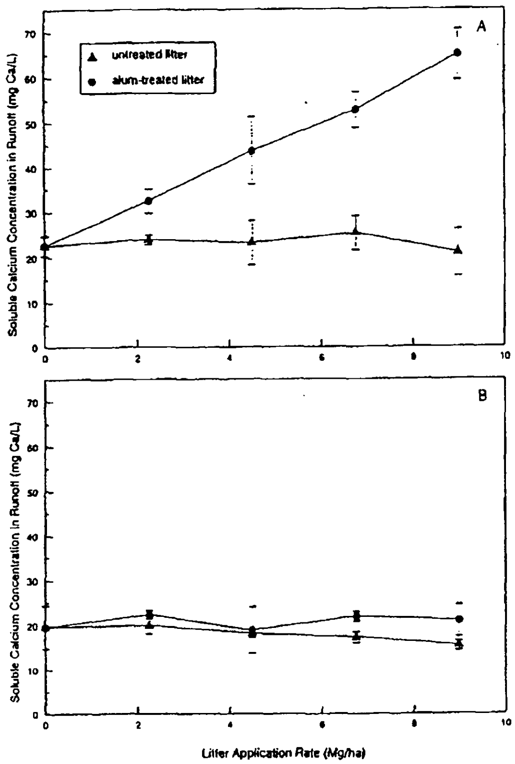

Fig. 7. Soluble Ca concentrations in runoff water from fescue plots fertilized with untreated and alum-treated poultry litter at (*A*) the day of application, (*B*) 7 d after application.

pronounced on Al concentrations as they were for As, Cu, and Zn (Fig. 6a,b; Tables 2 and 3). The highest litter application rates resulted in Al concentrations of 0.23 and 0.25 mg Al L^{-1} for the first runoff event, for alum-treated and untreated litter.

Unlike most of the other metals studied, water-soluble Al only accounted for a small fraction of the total, indicating that most of the Al runoff was associated with particulates which would not pass through 0.45 μm membrane filters (data not shown). The total Al content of the runoff from alum-treated litter was higher than untreated litter for the first runoff event, but the opposite was true for the second event. We suspect that the particulate Al in the runoff water was either amorphous $Al(OH)_3$ or gibbsite since the pH of the water was above 7.0, although we did not attempt to calculate activity products. Accurate calculation of ion activities in this system was not deemed to be possible, since the concentrations of various organic ligands present were not measured.

Soluble Al loads from the control plots were 22 and 23 g Al ha^{-1} for the first and second runoff events, respectively (Table 4). At the highest litter application rate the soluble Al loads were 36 and 40 g ha^{-1}, for alum-treated and untreated poultry litter, for the first runoff event.

Selenium

Selenium concentrations in the runoff water were all below detection limits (0.075 mg Se L^{-1}). However, we cannot speculate as to whether the levels in poultry litter runoff were safe or not, since the Se level needed for chronic toxicity (24-h average) is 0.035 mg Se L^{-1} (DPCE, 1988). Runoff concentrations of Se were well below that needed for acute toxicity (0.260 mg Se L^{-1}) (DPCE, 1988). U.S. Public Health Service (1962) limits the level of Se in drinking water to 0.010 mg Se L^{-1}. More research is needed on Se runoff from fields receiving poultry litter to ascertain if the new limits on Se levels in poultry feed (which were imposed based on environmental considerations) are warranted.

Macronutrient Runoff

Calcium and Magnesium Runoff

Calcium concentrations in runoff from the control plots were approximately 22.6 and 19.6 mg Ca L^{-1}, for the first and second runoff event (Fig. 7a,b). Calcium concentrations in the runoff water increased with litter application rate for the alum-treated litter, whereas they remained relatively constant in runoff from untreated litter (Table 2). The average Ca concentration at the highest litter application rate was 64.9 and 21.1 mg Ca L^{-1}, respectively, for alum-treated and untreated litter, for the first runoff event. Calcium solubility was probably higher in the alum-treated litter because it had a lower pH than untreated litter, as stated earlier. Although there was only a slight difference in the pH of the litter at the time of application, it should be noted that large differences in pH occurred when the poultry litter was first treated with alum when it was still in the poultry house. Litter pHs of 4.5 to 6.0 are relatively common after alum has been applied to poultry litter. These low pHs only last for a short period, as the manure from the birds contains large quantities of bases (ammonia, calcium carbonate, etc.), which consume the acidity released from alum. This process results in the dissolution of Ca and Mg carbonate minerals, such as calcite and dolomite, releasing Ca and Mg in the process.

Calcium concentrations in runoff 7 d after litter application were not affected by litter application rate, as in the first runoff event (Table 3). In fact, Ca levels in runoff from the highest rate of untreated litter tended to be lower than from the control plots (15.5 vs. 19.6 mg Ca L^{-1}). The highest dissolved Ca concentrations observed by B.M. Hall (1993. Broiler litter effects on crop production, soil properties, and water quality. Masters thesis, Auburn Univ.) in runoff on a 4% slope were 14.9 and 47.67 mg L^{-1}, under 9 and 18 Mg broiler litter ha^{-1}. Average dissolved Ca concentrations were 5.16 and 7.71 mg L^{-1} under 9 and 18 Mg broiler litter ha^{-1}. Magnesium concentrations followed the same trends as Ca (Tables 2 and 3). Magnesium concentrations in the runoff of the control plots were approximately 4 and 3 mg Mg L^{-1}, for the first and second runoff event (data not shown). Magnesium concentrations increased with increases in litter rates for alum-treated litter during the first runoff event, with the maximum rate of alum-treated litter resulting in Mg concentrations of 16 mg Mg L^{-1}, whereas there was no effect on Mg runoff from untreated litter.

Potassium and Sodium Runoff

Concentrations of K and Na in runoff water followed similar trends (Tables 2 and 3). The concentrations of both of these metals increased linearly with litter application rate for the first runoff event and tended to be higher from plots fertilized with alum-treated litter (data not shown). The regression equations describing K and Na runoff are shown in Tables 2 and 3. Potassium concentrations were in excess of 200 and 250 mg K L^{-1} in runoff from the highest rate of untreated and alum-treated litter during the first event. These values are more than twice the highest dissolved K concentrations in runoff observed by B.M. Hall (1993. Broiler litter effects on crop production, soil properties, and water quality. Masters thesis. Auburn Univ.) which were 54.79 and 110.29 mg L^{-1} under 9 and 18 Mg broiler litter ha^{-1}. Sodium concentrations were 65 and 75 mg Na L^{-1} in runoff from untreated and alum-treated litter at this time. Seven days later the concentrations of both K and Na tended to be lower with alum-treated litter.

CONCLUSIONS

Trace metal (As, Cu, Fe, and Zn) concentrations in the runoff water from plots fertilized with poultry litter were increased as litter application rates increased and were higher from untreated litter compared to alum-treated litter. The metal of greatest concern in poultry litter is Cu, which was found in extremely high concentrations in the runoff of untreated litter (1 mg Cu L^{-1}). Since Cu is extremely toxic to algae, it poses the largest threat of the metals studied to aquatic life. Copper concentrations and loads in runoff were significantly reduced by alum-treatment of litter. This practice has also been shown to increase fescue yields, reduce P runoff, inhibit NH_3 volatilization, as well as increase weight gains and improve feed conversion in broilers. Therefore, amending poultry litter with alum appears to be one of the few cost-effective best management practices that both reduces the negative environmental impacts of manure, while increasing agricultural productivity.

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